Science News

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Editorial

It takes six months from the day it goes to the printers for each issue of *Science News* to reach the bookshops. With the best will in the world, we cannot at present cut the time any shorter. The result is that though we try to keep close on the heels of the laboratory workers, we always run the risk of being six months out of date. Science sometimes advances very rapidly indeed, and though the facts do not change, their bulk expands, and their interpretation is liable to any number of somersaults. Consequently, we can offer no guarantee of perfection in our reporting from the fronts of scientific knowledge. It is inevitable that the reports will sometimes be misleading, because scientists themselves were misled at the time the printer started work. All we can promise is that nothing appears in these pages until the research on which it is based has received reasonable confirmation and acceptance in the scientific world: this means that it is a part of current thought, and *not* that it is a final conclusion. More we cannot do, if we are to act as guide in the progress of scientific ideas and results.

Is Science a Closed Shop? The advent of the atom bomb as the result of years of team work in vast laboratories filled with complicated apparatus, and the trend of professional scientific research to use ever more elaborate machines—electron microscopes, refrigerated centrifuges, betatrons—and demand more and more technical training of its recruits, is in danger of convincing the layman and the amateur natural philosopher that it is. There seems no place any more for the enthusiastic schoolboy or schoolmaster, the man with a scientific hobby for the winter evenings, the amateur naturalist working on his own. Yet in fact the amateur and the lone worker still occupy a very important place, and this issue of *Science News* draws

attention to some of the sciences where his contribution is valuable. Amateur astronomers have made many important discoveries in the past; radio has long proved a popular hobby; in "Detection of Meteors by Radar" Dr. Rabel shows how the two are now joining forces. Natural history is traditionally an amateur's field. In "Cave Science" Dr. Pavan reminds us of many problems waiting to be tackled at the bottom of pot-holes: speleology is almost entirely an amateur's science. Weather observation is another popular hobby: Dr. Kraus, though himself a professional meteorologist, writes of "Rain" in a way to interest the home observer. Anyone who reads Professor Aubrey Lewis's article on Mental Disease must be struck by the extent to which individual medical practitioners, often working on their own, have made important contributions to the subject. They possess that freedom to be bold which official bodies lack, but which the problem still requires. As a complete contrast—an approach to the workings of the brain through the study of single nerves, with the disciplines of physical science—we include Dr. Rushton's "How Nerves transmit messages". Finally we add our voice to the celebration of the hundredth birthday of the Chemical Society of London, with Dr. Sherwood Taylor's review of "A Century of British Chemistry".

Physical Treatment of Mental Illness

PROFESSOR AUBREY LEWIS

THE empirical methods of treatment introduced into psychiatry during the last 15 years had had the way prepared for them by Wagner Jauregg's great demonstration that general paralysis of the insane is not an inevitably lethal disease but one which can be arrested and, for practical purposes, often cured by malaria. The effect of this on the outlook of psychiatrists was so great, and the lessons of malarial treatment so relevant to appraisal of the later "shock" methods, that it is illuminating to consider very briefly how Wagner Jauregg's discovery came about and established itself. General paralysis of the insane had been a common diagnosis in mental hospitals, until the disease was recognised to be due to syphilis and laboratory tests were used to make the diagnosis more exact: then the number of cases was found to be smaller than had been thought. The disease was as fatal as cancer: an occasional patient might enjoy a long remission or drag out his life beyond the accustomed three or five years, but for almost all a series of downward changes leading to death in dementia could be predicted. Wagner Jauregg, however, took note of the old clinical observation that a long remission, or an apparent recovery, sometimes occurred in mental disease after a fever, and he decided in 1887 to turn this to account: the outcome was his use in 1917 of induced malaria. It was a bold experiment—to give malaria, itself a serious disease, to patients already doomed to suffer a debilitating syphilitic process: it could be justified only by the hopelessness of the disease and the impossibility of making the therapeutic experiment

unconsciousness in spite of the administration of sugar, and the more experienced the people in charge of the "insulin unit" the less frequent is the occurrence of this alarming complication, though even so it cannot be wholly prevented. The other serious risks, such as intercurrent affections of the lungs or heart, are rare in a well-conducted unit.

The treatment was instituted for schizophrenia, and schizophrenia has remained the condition for which it is judged appropriate: it has been tried in other mental illnesses with little or no benefit. Schizophrenia, however, is not—like general paralysis, or diabetes, or coronary thrombosis—a well-defined disease with unequivocal characteristics: the term is made to cover a wider range of illness in one country than in another, and may be used somewhat differently even by different doctors in the same country, some restricting it to a smaller core in which the symptoms are indubitable and mostly intractable, others applying it to a more heterogeneous collection of disturbances, having certain basic features in common but diverging widely in pattern and outcome. The future of the individual patient is in any case hard to trace with confidence: if he becomes well after insulin treatment it cannot be certain that this would not have happened with more routine methods of treatment. Consequently the results of treatment not only appear to differ widely in reports from the clinics in different countries, but they cannot be judged through study of individual patients, except where the patient has been ill so long that his recovery seems quite beyond hope—and such patients with long established schizophrenia are by common consent unresponsive to insulin treatment. The results of the treatment must therefore be assessed by statistical comparison of a sufficiently large group of insulin-treated patients with another group, untreated with insulin but chosen to match the insulin group in respect of all those factors which affect prognosis: both groups must be observed not merely at

the end of treatment or as long as they are in hospital, but for two or more years afterwards to see how lasting is their improvement or their deterioration.

Such comparisons have been made. The fullest is that reported from New York State. The 1,128 patients of the insulin group had been treated in Brooklyn State Hospital, the control group (876 patients) in other mental hospitals in the State. Seventy-nine per cent. of the insulin group had been able to leave the mental hospital as against 58.8% of the control group. The insulin patients spent on the average 3.8 months less in hospital than the control patients. Among the patients who had to be readmitted to hospital, the insulin patients spent on the average two months more at home than in the hospital whereas the control patients spent 7½ months more in the hospital than at home. At the end of the period of study 59% of the insulin patients were at home, as against 44% of the "non-treated" group. Seventy-one per cent. of the insulin patients were earning their living, compared with 60.6% of the control patients. Such results seem to show a decided advantage in insulin treatment. They can, however, be criticised: the recovery rate is exceptionally high, and for some of the subgroups improbably so; the Brooklyn Hospital receives a higher proportion than other New York mental hospitals of the acute catatonic cases (which on the whole have a good outlook), and it discharges patients very early, with in consequence a higher relapse rate (42.5%) among the discharged insulin patients than among the discharged control patients (31.5%). But even allowing for these sources of possible error the New York figures make a strong case for the beneficial effect of insulin treatment.

The results of insulin treatment in the mental hospitals of Denmark were collected in 1941. Of the 276 schizophrenic patients treated 162 were classed as having indubitable schizophrenia, 114 were regarded as slightly dubious (though they would almost certainly have been classified

as schizophrenic in any American or English statistics). Just over a quarter of the indubitable schizophrenics showed some improvement after insulin but half of these relapsed within a year; for the "dubious" schizophrenics the corresponding proportions were 50% improved, of whom approximately 40% relapsed. The authors of the report conclude "only very few cases of indubitable schizophrenia were cured but in a certain number of cases an improvement was obtained which justifies fully the continuation of this treatment. In non-typical cases of schizophrenia the results were considerably better; and the best results were obtained in psychogenic psychoses."

It is unnecessary to review further the rather discrepant reports, many of which are favourable. The bulk of reliable observers make the modest but confident claim that insulin treatment of schizophrenia effects better results than any other method, though it fails to benefit many patients, especially those with illness of long duration and ominous clinical features. Where observers compare the insulin results with those obtained by other standard treatment, the superiority of insulin is less evident (or is hardly evident at all) in those clinics which had a very high standard of therapeutic effort before "shock methods" came on the scene. It is true that enthusiasts for insulin treatment consider that in the clinics in question the new method was not carried out thoroughly enough to give its best results, but it is generally the case that those who worked in therapeutically active clinics are less impressed by the benefits of insulin than those who had previously taken an unduly pessimistic view of the outlook in schizophrenia and been disposed to think their diagnosis might have been wrong if the patient recovered.

The *modus operandi* of insulin was, in Sakel's original theory, upon the nerve cells and the hormones which, he believed, excited their activity especially in the "vegetative centres" (*i.e.*, parts of the brain controlling internal organs). His theory was elaborate and pretty well stillborn. Other

explanations were put forward, most of them stressing the interference with brain tissue respiration entailed by the insulin, others pointing to the disturbance it causes in the autonomic nervous system, and a few insisting on a psychological explanation in terms of impending death and re-birth. One experimental study, made on rats, demonstrated that coma produced by insulin would restore previously inhibited conditioned reflexes, and this has been applied to what happens in human beings. It is, however, impossible at present to do more than describe some of the physico-chemical accompaniments of insulin treatment: knowledge of the relation these have to clinical improvement must await recognition of the essential bodily changes characteristic of schizophrenia.

Induced Convulsions

The treatment of mental illness by induced convulsions was based on the same sort of clinical observation as Wagner-Jauregg's introduction of malaria. Some patients with the catatonic variety of schizophrenia had become well promptly after they had a spontaneous convulsion; moreover, epileptic fits occur only rarely among schizophrenics (thus a Swiss investigator found only eight epileptics among 6,000 schizophrenics). A Hungarian psychiatrist, Nyiro, therefore tried the effect of transfusing the blood of epileptic patients into schizophrenics. The experiment was unsuccessful, but Meduna (following the same line of thought, which supposed that there must be some antagonism between the two diseases) decided to induce convulsions in schizophrenia. He made some experiments on animals which satisfied him that artificial convulsions do not cause serious damage to the central nervous system, and then by injecting camphor and later by intravenous injection of penta-methylene tetrazol, he carried out the human therapeutic experiment. The results were sufficient to encourage him to continue; after he had published his results, the method was quickly taken up

all over the world. It had the advantage over insulin that it was easier to administer, not requiring such close medical and nursing attention, and the risk to life was slight. There were however other risks, presently to be mentioned.

Two major changes were effected in the treatment during the next five years: it was recognised to be less effective for schizophrenia than for melancholia, especially the melancholia of later life, and instead of drugs an electric current was used to produce the convulsions. The former clinical observation showed, as did more accurate statistics of incidence, that the theory of a supposed "biological antagonism" between epilepsy and schizophrenia had no substance, and that the introduction of this treatment had therefore been a lucky shot in the dark, at the wrong target. It was recalled that in the eighteenth and early nineteenth century camphor, in quantities sufficient to cause convulsions, had likewise been recommended for various forms of mental illness, but no systematic trial of the procedure had been made.

Other accidents or by-products of investigation led to the substitution of electrically induced convulsions for drug-made ones. As Delay says of this: *Il faut chercher pour trouver, mais non pour trouver ce qu'on cherche—c'est le paradoxe de maintes psychologies de la découverte.* A German neuro-pathologist, Spielmeyer, had called attention to the sclerosis (hardening due to excessive fibrous tissue) observed in a particular part of the brain of epileptics, and questioned whether it was a cause or consequence of the fits. Cerletti, an Italian neurologist and psychiatrist, decided to investigate the matter by inducing convulsions in dogs by the passage of an alternating current through the brain, and with his associate Bini succeeded in doing this without permanent damage to the animal. Further observations on pigs at the Rome abattoirs convinced Cerletti that it was safe to apply this method of inducing fits to human beings, as indeed some French and Swiss observers had shown in 1903-7. Meduna's method had

certain obvious disadvantages—intravenous injection is sometimes mechanically difficult, especially after it has been carried out several times into the same vein; and, for a few moments before drug-produced convulsions, patients often experience a most distressing aura, the memory of which remains and makes them fear subsequent treatment. Electrical methods of inducing the convulsion avoided this, and are now almost invariably used, though there is some variation in the technical procedure, according to the instrument employed. Most psychiatrists have applied to the brain an alternating current of voltage between 50 and 150 volts, for a period ranging from a tenth to half a second.

The risks of the treatment are almost entirely due to the motor excitation. Thus dislocations or fractures may be caused by violent movements in the convulsion: chemical means can be employed to prevent such mishaps, but there are in turn some objections to the routine use of the drug (curare) appropriate for this purpose. Respiratory and circulatory complications can usually be foreseen and forestalled if there is thorough preliminary examination. Patients with pulmonary tuberculosis or a number of other systemic diseases may have their condition aggravated if given convulsions: but it is mostly a question of weighing the advantages against the risks in the given individual who has one of these diseases, rather than putting up an absolute bar against treatment by convulsions. Some observers, pointing to the severe damage to the brain in accidental electrocution, and to the impairment of memory which may follow the series of convulsions, have concluded that cell destruction must be reckoned as part of the price that may have to be paid for this treatment: but there is no conclusive evidence that there are permanent changes of any consequence in a previously healthy brain after a series of twelve or so convulsions.

The results of this treatment are reported in a large number of divergent papers, agreeing only about the

anterior part of the frontal lobe with the dorsal median nucleus of the thalamus. The subsequent mental state of the patient may be like that of a person who has received a severe injury to the brain in an accident: he may become tactless, outspoken, careless, self-satisfied and without initiative. But these consequences are by no means always evident: in some patients even a skilled observer can detect little amiss once the immediate effects of the operation have passed off, whereas in other patients the subsequent condition amounts to a dementia; between these extremes many gradations may be seen, partly dependent on the previous personality and the illness of the patient in question, and partly on the location and extent of the cuts made through the frontal white matter. Psychological tests show that there is no impairment of formal intelligence as a rule: the subjects gain as high a score on standard intelligence tests as they had before the operation. In the practical affairs of life, however, many of them do not behave intelligently, and a number of psychologists have therefore tried to determine and measure the impairment in adaptive functions which this practical inefficiency connotes. It has been observed, for instance, that in the well-known Porteous Mazes those who have had a leucotomy (the name commonly given in this country to the operation) are at a disadvantage, since they do not look ahead. They do badly in other tests which are designed to measure capacity to hold back a motor impulse or persistence in attaining a goal one has set oneself. Study of the deficit produced by the operation is in its early stages, but has double importance: it will illuminate the way in which an interruption of fronto-thalamic nervous connections benefits certain forms of mental illness, and it will enable us to assess the price the patient pays for the benefit. The price may be a high one: apart from gross disturbances such as epilepsy (which are not unknown as effects of the operation) permanent blunting of the patient's sensitiveness and restraint may have to be reckoned with. On the other

hand, these residual handicaps may be judged trifling, when set against the severe symptoms which the operation relieves. Obviously frontal leucotomy is not to be undertaken lightly, after a few months' trial of less drastic measures; the decision calls for a thorough appraisal of the social as well as the more narrowly medical issues in the individual case.

The patients who benefit most are those who are ceaseessly harried by painful ideas, or are given to outbreaks of uncontrollable violence. The more signs of emotional tension beforehand, the more gratifying the result. Whether the patient has a schizophrenia with persistent delusions and hallucinations, or an obsessional illness with persistent fears and impulses, the leucotomy, if effectual, will not usually abolish the morbid ideas but will make them bearable and unimportant to him: it is, in short, an operation to alleviate symptoms, rather than to end a disease. The symptoms may be of the kind that make it imperative for the patient to be nursed in a hospital, because of his outbursts of excitement: after the operation he may be no longer thus destructive and violent, so that he can return to his home or at any rate lead a quieter life in the hospital. In the recently collected findings of a thousand patients treated by leucotomy in this country, there were 364 recorded who had been violent before the operation; 260 of these were improved in this respect afterwards. There were, in this series, 757 patients whose illness had been going on for two years or more before the leucotomy: after it 173 of them were able to leave the mental hospital and were not known to have relapsed later. Of the 757, 489 were diagnosed "schizophrenia" and 150 "manic-depressive"; 15% of the former returned to live at home, and 38% of the latter.

Empirical Treatment

It is clear that these methods of treatment—insulin, convulsions, leucotomy—are not specific or, as yet, rational.

Like all empirical treatment that is not specific (in contrast, say, to the use of quinine in malaria) their development had to go through a hit-and-miss stage, the length of which depends on the care with which the therapeutic experiments are planned and conducted in order to disclose the range and mode of operation of the methods and the clinical indications for their use. And, like all methods of treatment in psychiatry that are not concerned with diseases having an established pathology and course (in contrast, say, to general paralysis) opinion as to their efficacy has to be judged in relation to a recovery which could have occurred without this intervention, either because the illness tended towards recovery anyhow or because other methods of treatment were being employed concurrently with benefit. It is impossible, of course, to deal with the patient as though he were a laboratory animal and to abstain from doing anything to help him except carry out the special physical treatment: if he cannot sleep, sedative measures must be employed; he will take part in the organised routine and occupations provided in the hospital; the doctor will see him and their conversations will inevitably have a therapeutic intention; and, indeed, the special treatment itself induces a temporary illness and dependence which demands nursing or medical attention to a degree that may have much psychological effect upon the patient. In a slightly older method of physical treatment—continuous narcosis (drug-induced sleep)—many psychiatrists believed that the virtues of the treatment actually resided in this induced helplessness which made the previously isolated and inaccessible patient receptive to psychological treatment.

It is generally conceded that in the main the patients who respond best to insulin or convulsions are those for whom the prognosis would have been good in any case: the newer methods of treatment shorten the illness, it is claimed, or prevent secondary products of the illness (*e.g.*, resentment at being a long while in hospital), but they do

not, for the most part, turn a hopeless into a remediable condition. This obviously makes it harder to tell how much the special treatment has contributed to a recovery which could have occurred without it. Statistical comparison of sufficiently large and well-matched series of cases treated and not treated by the method is the proper recourse in such a difficulty: it has been employed by L. S. Penrose and many other investigators.

Insulin, convulsions and leucotomy do not exhaust the physical methods of treatment lately introduced into psychiatric practice. Continuous narcosis, brought into use in 1922, has already been referred to: it has its success in much the same kind of illness as convulsive treatment. Drugs such as amphetamine sulphate (benzedrine) and choline derivatives have been employed systematically. A "conditioning" method which makes use of a drug that causes vomiting has been effective with some addicts to alcohol. Nitrogen inhalations; faradic stimulation; "electrical narcosis"; artificially produced fever, sometimes combined with convulsions; and "refrigeration therapy" (in which the temperature of the body is reduced below 85°) have been tried, in accordance with some dubious theory or dubious observation, and for the most part have soon been dropped, as too dangerous or ineffectual.

Periodic Catatonia

The difference between empirical procedures and a rational psychiatric treatment may be seen on comparing them with Gjessing's work on periodic catatonia.* Gjessing, a Norwegian psychiatrist, began about twenty years ago a painstaking study of the metabolism of the very small group of patients in whom repeated attacks of catatonic stupor or excitement occur in a regular sequence: the condition is usually included in the larger class, schizophrenia, and is by some thought to be a blend of schizophrenic and manic-depressive illnesses. In a period of

* See glossary under "psychiatry" for all technical terms.

13 years Gjessing investigated ten such cases over a total of 3,500 days. Having excluded all complicating influences such as chronic infections, he put his patients on a strict diet, and carried out daily biochemical examination of their blood, urine and fæces. He discovered that in place of the normal regular nitrogen excretion, periods of excessive excretion and excessive retention alternated, consistently related to the mental changes. In one type excitement or stupor sets in just after the time of maximum nitrogen retention, and lasts while over-excretion is going on to get rid of the accumulated nitrogen; in the other type the excitement or stupor sets in just before the time of maximum excretion and lasts for the greater part of the period of retention. A given patient will always exhibit the same type of relation. The assessment of the mental state and observation of its changes was made as objective as accurate records and the use of appropriate instruments could ensure. It seemed possible that the changes in nitrogen output might be dependent on excessive muscular activity (and under-nutrition) during the phase of excitement; but the second type of relation put this out of court, since the excitement there coincided with nitrogen retention. For this and other cogent reasons Gjessing concluded that the phasic disturbance of nitrogen metabolism constituted the fundamental pathology of the disorder, the mental changes being merely the outward symptoms. If, then, the metabolic anomalies could be prevented, the mental state would remain normal. The chief (though not the only) metabolic anomalies concerned nitrogen storage and excretion. Thyroxin is known to deplete the body's nitrogen store and thus increase excretion. Gjessing therefore gave a large dose of thyroxin (40–50 mgm) over 8–10 days to prevent any retention of nitrogen: a considerable loss of nitrogen and of body weight, occurred. He then gave maintenance doses of thyroid to keep the nitrogen store low. By this means, and insistence on a milk and vegetable diet with low protein content, the phasic changes in nitrogen output

came to an end. The patients he treated in this way remained free from mental symptoms for years.

Patients who have true periodic catatonia are few and far between, and the results obtained with them cannot be paralleled in other catatonic patients or in patients with other periodic mental illnesses. But the object lesson provided by this tiny group and the patient work of Gjessing on them needs no underlining.

A similar though less telling object lesson is afforded by tryparsamide, an arsenical drug, the product of extraordinarily careful systematic research, which is beneficial in trypanosomiasis and in general paralysis. Penicillin too is now being used for general paralysis. But Gjessing's work stands out since the condition he treated had been regarded not as a symptomatic psychosis, in which the mental features are manifestations of a known physical disease, but as a form of schizophrenia.

There are many who hold that psychoanalysis is likewise an object lesson in rational therapy. If the theory of psychoanalysis be accepted, then this contention must be upheld. There is however still, as everybody knows, much controversy about the correctness of the theory, and some uncertainty about the efficacy of the therapy. It is not necessary or appropriate to examine the views and evidence here; certainly psychoanalysis exercises a great influence upon psychiatric thought and practice. It is now more than fifty years since Freud and Breuer published their historic paper. Psychopathology and psychotherapy have developed during that half century in very intimate association; and if psychopathology rested on observations as easily made and verified as those of somatic pathology, there would now be little chance to wonder whether psychotherapy is rational or empirical. The same can be said of social methods of treatment which are now widely utilised, through the agency of the trained psychiatric social worker. Many methods have been brought forward of late years to widen the scope or intensify the action

of social and psychological treatment: "group psychotherapy" is such a method which now occupies much attention. In all of them, however, it is plain that working out a technique of treatment, constantly modified in the light of individual or collective experience, is enforced by day-to-day clinical needs, to the detriment of therapeutic experiments planned with something of the same care as a laboratory investigation. This is almost unavoidable, as anyone may see who reflects on the complexity of psychological aberrations and their treatment, and knows what strong pressure to do something active and confident is brought to bear on the physician who undertakes such treatment.

This pressure of human need, always an important factor and the chief incentive in the development of therapeutics, has been responsible in psychiatry (as in other branches of médicine) for some wrong turnings and hasty expedients. In psychiatry, moreover, animal experiment can give little help as the preliminary testing-ground for remedies, since the main patterns of mental illness cannot be reproduced in other animals. For that vast part of mental illness which has as yet no known bodily basis, man alone can be the subject of crucial experiment; and although therapeutic experiments on man can be daring, as Wagner Jauregg and many others have shown, they cannot in a normal society be well controlled. Fuller said of the good physician that "he handsels not his new experiments on the bodies of his patients, letting loose mad receipts into the sick man's body, to try how well nature in him will fight against them, whilst himself stands by and sees the battle: except it be in desperate cases when death must be expelled by death." The good psychiatrist, though he recognises that the issues in mental illness are desperate enough, is averse from over-bold enterprises in treatment; but he is in the predicament, as other doctors have been too, that he must either wait until research throws more light on the causes and pathology of the diseases he treats,

or he must try any new measures, from the outset, on volunteers who are aware broadly of the chances of improvement and the risks or uncertainties the treatment presents. This is in respect of new measures: for established treatment, the psychiatrist already has at his disposal a body of therapeutic experience and many procedures, both rational and empirical. The good results, though patently insufficient, bear comparison with what is attained in other branches of medicine.

Detection of Meteors by Radar

DR. G. RABEL

What is Radar?

FOR a long time past Radio Direction Finding has assisted in determining the position of a craft both in the air and on the sea. The aerial used for this purpose is a frame which can be made to rotate about a vertical axis. If the frame is set edge-on to the direction from which a signal is coming, the aerial gives maximal response. If it is turned round by 90 degrees so that the plane of the frame is perpendicular to the path of the signal, the response is zero. Thus the bearing of a signalling coastal station with respect to a ship can be ascertained, and if signals are taken from two or more radio beacons, the point on a map where these lines of bearing intersect gives the position of the ship.

R.D.F., then, requires the cooperation of some outside station—though, it is true, this cooperation may be entirely involuntary, as for example when an illicit transmitter reveals its presence.

The distinctive feature of Radar, or Radiolocation, is that it needs no cooperation whatever on the part of the object but works on its own, by sending out signals into space and watching the echoes which come back.

The fact that electromagnetic waves are of the same nature as light waves and can, like them, be reflected and refracted (bent) was demonstrated by Heinrich Hertz in 1888. When waves pass from one medium into another medium of different electric properties, *e.g.*, from air into water, one portion of the radiation is thrown back into the first medium, while another portion enters the second medium and becomes refracted. For instance a stick lying part in water and part in air looks as if it were broken,

because the light rays from the under-water part are bent on crossing the surface into the air.

If the boundary surface is smooth, *i.e.*, contains no irregularities or ripples of the same order of magnitude as the wave length, the reflection is regular as from a mirror. If there are considerable irregularities, the incident rays are scattered in all directions as when light falls on frosted glass.

The time a wave takes to go out to an object and come back, depends evidently on the velocity with which it travels and the distance of the target. These three quantities are connected by the simple equation

$$\text{velocity} = \frac{\text{distance}}{\text{time}}, \text{ or distance} = \text{time} \times \text{velocity}.$$

The time for the round trip can only be measured if the moment of sending is precisely defined, that is if the transmission is interrupted. Fizeau was the first to introduce this method when he undertook to measure the velocity of light. He used a toothed wheel to provide periodical interruptions. To-day short "pulses" of a limited number of oscillations are sent out.

Fizeau knew the distance his rays had to traverse, hence by measuring the time they took he obtained their velocity. The radiolocator knows the velocity of his rays, hence by measuring the time he obtains the distance.

The Cathode Ray Oscillograph

As the velocity of radio waves in air is the same as that of light, namely 300,000 kilometres per second, a signal takes only 0.001 seconds or one millisecond to travel 300 km., and only 0.00001 seconds or ten microseconds to travel 3 km. No mechanical device could react quickly enough to make exact measurements of such time intervals, and wherever extremely quick response is required, the Cathode Ray Tube Oscillograph is put into action.

The main principle of this device, leaving out details, is this: an evacuated glass vessel in the form of a cone contains a pair of electrodes connected to a battery. The

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Fizeau knew the distance his rays had to traverse, hence by measuring the time they took he obtained their velocity. The radiolocator knows the velocity of his rays, hence by measuring the time he obtains the distance.

The Cathode Ray Oscillograph

As the velocity of radio waves in air is the same as that of light, namely 300,000 kilometres per second, a signal takes only 0.001 seconds or one millisecond to travel 300 km., and only 0.00001 seconds or ten microseconds to travel 3 km. No mechanical device could react quickly enough to make exact measurements of such time intervals, and wherever extremely quick response is required, the Cathode Ray Tube Oscillograph is put into action.

The main principle of this device, leaving out details, is this: an evacuated glass vessel in the form of a cone contains a pair of electrodes connected to a battery. The

negative electrode, called the Cathode, which is placed at the narrow end of the tube, is heated by an auxiliary current so as to emit a considerable stream of negative electrons. These wander towards the positive electrode near by, called the Anode, and as the anode has a small hole in its centre, some of them move on through it and all through the length of the tube until they hit the broad end. This end is formed by a screen of fluorescent material and each time electrons hit that screen, a bright spot of light appears on it.

If somewhere between the anode and the screen two metal plates are fixed to the right and to the left of the tube, one of them charged to a positive, the other to a negative potential, the electron beam emerging from the cathode will be deflected towards the positive plate, and if the plates are alternately charged positively and negatively, the electron beam will follow suit and oscillate from the right to the left and back.

In practice, one of the plates is connected to a condenser which is periodically charged and then discharges itself quickly. Hence the electron beam sweeps horizontally across the screen and suddenly returns to the starting point. This movement of the electron beam is called "the Sweep" and the bright horizontal line it traces from left to right on the screen is called "the Time Base". The sweep is so adjusted as to work in time with the pulse transmitter. It starts at the utmost left corner each time a new pulse is sent out and moves over the screen with uniform speed. Therefore the distance of a point on the time base from its left end can serve as a time scale. If another electric field is applied perpendicularly to the first, that is above the tube and below it, it deflects the electron beam upward and downward.

In radiolocation, the incoming (reflected) radio waves supply the potential for the vertical electric field. But some grooming is needed before they can produce the desired effect. The waves are rectified, which means that their

oscillatory electric force is transformed into direct current by the omission of one half cycle in each full wave. Then they are amplified because otherwise they would be too feeble. Thus prepared, it is they which deflect the electron beam away from the time base.

The times at which such deviations occur are easily measurable on the horizontal base, and as the travelling speed of electromagnetic waves is a known and constant factor, the scale can be graduated in kilometres (or miles) so that one glance on the scale provides direct, without further computation, the distance of the target. If the target moves, the bright pulse spot moves along the screen either towards the starting-point of the baseline or away from it. In modern equipment the azimuth of the object can also be read direct from a horizontal scale and the angle of elevation from a vertical one.

Only a few pulses are sent out in every second, because it is essential for the method that the energy from the reflected wave shall have died away before the next signal goes out. A station may send out, say 25 pulses per second, each lasting ten microseconds. That means that the whole span of time occupied by the signals is only 0.000250 seconds, or as the wireless man puts it: "the transmitter marks 250 microseconds". This very small "mark/space ratio" is characteristic for radar transmitters and explains the fact that very high pulse energies can be obtained. Suppose the peak power to be 800 kilowatt, the mean energy over a second would nevertheless only be

$$\frac{800 \times 250}{1000000} = 0.2 \text{ kilowatt or } 200 \text{ watt.}$$

When the attention of the wireless world was called to the fact that radio waves are reflected from layers of ionised gas in the upper atmosphere (the Ionosphere), scientists both here and in other countries set themselves to study these echoes systematically and soon they observed abnormal echoes of very short duration which seemed to

come from passing meteors. A great number of these transient echoes were noticed during the Leonid shower of 1931, for instance.

Sir Edward Appleton suspected that passing meteors might be responsible for irregularities in the ionisation of the upper atmosphere, and therefore careful watch was kept over them.

However, it seems that the main interest aroused by this technique was at first directed to the practical implications of the phenomenon. Could not terrestrial objects, ships and aircraft, be detected by the same method? As early as 1931, the British Post Office made experiments on five metre wave length for this purpose and it was definitely established that a flying aeroplane, even if invisible, can be detected by a ground receiving apparatus.

In 1935-6 the first exploring station was installed at the east coast of England. Long before the war the system had been made foolproof for unskilled operators. The scientific exploration of the ionosphere together with the practice of direction finding has thus generated in this country the technique of radiolocation. The American term Radar was later adopted because it is shorter.

Meteors

Meteors (shooting stars) as a rule become visible at a height of 100 kilometres. As they enter the atmosphere with a terrific velocity, their impact upon the gas molecules of the air has two effects: heat and ionisation. A brilliant white light flashes up and columns of glowing ionised gas are left behind in the wake of the meteors, slanting down towards the earth. When they have reached a height of about 70 kilometres, the meteors are usually reduced to ashes, and vanish.

Most meteors are extremely small, like grains of sand, their radius being a fraction of a centimetre and their weight a few milligrams. A small percentage of them are larger; these manage to penetrate the atmosphere and to land on

our earth. The well-known meteorites are exceptionally large ones.*

It is now often assumed that most meteors, if not all, are crumbs spilled when a comet hits on the atmosphere of our own or some other planet. An impressive example was supplied by the thrilling adventures of Biela's Comet. When this comet, whose period is $6\frac{3}{4}$ years, came near the earth in 1845, it consisted of two bodies which moved side by side slowly separating from each other. In 1852 they were farther apart. Neither in 1859 nor in 1866 was the comet sighted at all, but on the 27 November, 1872, it reappeared—this time transformed into a wonderful display of meteors. Since then the shower has repeated itself regularly, though with varying intensity.†

It looks as if roughly speaking meteor showers keep moving on the same track as their parental comet and that hence meteors, like the comets, belong to what has been called "the obedient family of the Sun", which revolves round the Master and follows him on his journeyings through the universe.

Meteors are known by two different names, a practice which is liable to confuse the layman. They have a family name derived from their real ancestor and a topographical name which designates their "radiant", the corner of the sky, the constellation, or to use for once astrological style,

* Even the small percentage of larger meteors is said to amount to 146,000 millions a year and it is estimated that in 3000 years the mass of the earth has increased by 1 million tons thanks to these arrivals. However, even a million tons is a trifle as compared to the total mass of the earth.

† An amusing comment to this story is given by C. Olivier in his book on Comets. Professor Challis in Cambridge saw on and after January 15, 1852, two comets instead of one, but "he was troubled by many misgivings, having it evidently in his head that no well-behaved comet ought to divide into two. On the 24th he was finally convinced." He explained that he could not devote much time to a comet caught in the act of multiplication because he was busy searching for Neptune. "1846 was a year of hard luck for the professor. . . . He and Airy share the serious blame for losing for England the undisputed priority in the discovery of Neptune and here he lost another opportunity for making a unique observation."

the "House" from which they seem to emerge. Thus the Bielid shower is identical with the Andromedids and the shower connected with the Giacobini-Zinner Comet which was observed in the autumn of 1946 is also named the Draconids.

It is rather surprising that a comet or shower whose period is anything between 3½ and several hundred years should, when it comes back, be met by us always at the same time of the year and coming out of the same house. We can only understand this phenomenon if we realise that the orbits of comets are very different from that of the earth, which is almost a circle. They are enormously elongated ellipses of which only a short piece lies in the neighbourhood of the sun while the rest stretches far out into space. A comet may come as near as five million miles to the sun (the nearest is 90,000 miles) and then escape very quickly and run as far away as 3,300 million miles. Such an orbit could almost be pictured as a very long pin with its head near the sun (perihelion) and its pointed end very far off. If a body travels along such a narrow orbit, it is plausible that when it comes back to the sun at all it comes back to the same house so that we encounter it at the same stage of our revolution round the sun.

Another at first sight paradoxical fact is this: if the period of a comet and its accompanying meteor throng is n years, how is it possible that we do not encounter members of this shower every n years only, but much oftener, in many cases actually every year? The answer is that as the shower goes on, it distributes itself evenly over the whole orbit and the longer a comet has sojourned in our solar system, the more uniformly scattered is its meteor stream. The Perseids, for example, or the Orionids, are met every year in about equal strength, whereas the Leonids, introduced into our solar system as late as 126 A.D. (when Tempel's Comet came into dangerous proximity to the planet Uranus) are not so evenly disseminated yet. On a bit of their track which takes three years to pass

the earth they are closely packed and during these three of their 33 years' period they provide beautiful fireworks (unless another planet attracts them too much as happened in 1899); for the other thirty years, only a few of them are met annually.

We are now, at long last, prepared to come to the gist of this story and to speak of its hero, the Comet Giacobini-Zinner. A feeble shower from this comet was observed in 1926. In 1933, the earth passed the comet's orbit at a distance of 560,000 miles and the result was the finest meteor display of this century. It lasted 5½ hours and 400 meteors per minute were counted at the peak. In 1939, the distance was much smaller but the earth passed the node—that is the point where the orbits cross—4½ months before the comet did, and no meteors were seen.

In 1946, all circumstances promised to be exquisite. The earth was to reach the node only fifteen days after the comet and only 132,000 miles off from its orbit. No wonder that there were great expectations.

Meteors and Radar

This time it was not only astronomers but also radio experts who stood at attention to await the illustrious visitors. They had already gathered considerable knowledge about meteors on former occasions. They were aware that the radar sets used for the study of the ionosphere were not suited for astronomical observations and had prepared a special directional beam aerial; that means that instead of broadcasting indiscriminately into space, the aerial radiated energy only into a narrow channel and could be pointed in any direction.

Hey and Stewart had obtained hopeful results with radio echoes on January 3, 1946, when the Quadrantid shower, and on April 20-22, 1946, when the Lyrid shower was due. The echoes coincided to a certain extent with visual observation. Also when beams from different stations were directed towards the shower, and the direc-

tions established from which the echoes were strongest, plotting these directions on a chart revealed the radiant of the shower in good agreement with other computations.

This gave confidence that the echoes actually came from the meteors in question, but if radio echoes did no more than just confirm visual observations, they would not be the great triumph and promise for science they are.

In fact, thirty per cent of the echoes received appertained to so-called telescopic meteors which cannot be seen with the naked eye and are only detected if perchance they pass through the field of vision of a telescope.

Radio echoes do not come from the meteors themselves but from the lengthy filament of highly conducting gas which forms their trail or streak. The echoes are observed when the beam is directed at right angles to the length of the trail.

In one set of observations undertaken by Dr. Lovell and coworkers, about 1,000 echoes were analysed. The work was done on a frequency of 72 Mc (million cycles), per second, which corresponds to a wave length of 4.2 metre. The transmitter radiated 150 pulses per second, each lasting 0.000008 seconds. Peak power was 150 kilowatt. The activity of the Draconid shower was confined to a few hours on the 10th October from midnight till 6 a.m. The peak was reached at 3.40 with 168 echoes per minute; five minutes after the peak only fifty echoes per minute were left and at 6 a.m. the rate had decreased to 0.03 per minute which is normal in showerless times. The very rapid rise and decline impressed the observers and further they noticed a dissymmetry between ascent and decline which seemed to indicate that conditions before and after the peak were somehow different, though what really happened is not yet clear (see plates 17 and 18).

Most echoes were extremely transient, lasting hardly one half second. Visual observers were disappointed because both here and in America the weather was unfavourable—too many clouds and at the same time too much moon-

light. By combining the results of several observers, however, a curve was obtained which showed, like the radio echoes, the very short duration of the whole shower and its rapid rise and decline. The maximum really observed was 16 meteors per minute, which, with some corrections, grew to 37.5.

But even the highest counts remained very far below those of 1933 when the conditions seemed so much less favourable. Meteors, if no longer a by-word for sheer caprice, are still not the most reliable inhabitants of this world.

J. S. Hey applied an ingenious method to measure the velocity of the meteors in a simpler and more accurate manner than astronomers could. There is a faint trace of an echo due to ionisation in the immediate proximity of the meteor. Then follows the main echo from the long ionised column. From the faint trace associated with the meteor itself as read off the time base the velocity could be computed and was, as an average from 22 cases, found to be 22.9 km. per second—in good agreement with other estimates.

Almost 23 kilometres per second is really a remarkable velocity. A meteor would travel from London to Cambridge in four seconds. If meteors at such speed meet the earth which itself speeds on at about 29 km.p.s., their velocities add up to more than 40 and the ionised trails produced by such impact are easily detectable. For the few meteors whose speed is greater than that of the earth, and which therefore are able to overtake it, the energy of impact is given by the difference between the two velocities which is small so that these meteors are not easily detectable.

But from now on astronomers will no longer be depending on what their eyes can see. They will neither be depending on good weather nor on the darkness of night for their work. When at a meeting of the Royal Astronomical Society Sir Edward Appleton inquired whether a maximum of meteor echoes at noon which he had found, corres-

ponded to any astronomical reality, he was told: "On the distribution of daylight meteors the visual observer cannot say anything. We must leave it entirely to the radio observers to investigate these."

The astronomer Mr. Prentice said: "This beautiful new technique represents a major advance. We feel like the first possessors of a telescope, unexpectedly armed with new powers of observation."

By means of the narrow beam aerial array, the meteors of an individual stream can be studied in isolation, and a continuous record of the activity of a given shower can be maintained year by year, which was impossible hitherto. Further, the fact that meteors can be observed in daylight enables a search for new streams which can never be seen by the eye. Indeed, quite recently, in 1947, Lovell discovered the great Pisces-Aries-Taurus stream active from May to July, far wider and richer than any of the annual streams with which we are acquainted in the night sky.

When the European war was over, plenty of radar sets and radar teams in this country were unemployed; Sir Edward was asked to find work for them and he suggested they should detect sporadic meteors. So there exists now a huge and interesting collection of data taken round the clock for almost a year. The results are not yet available, but already Appleton and Naismith see their assumption confirmed that it is these sporadic meteors which keep up ionisation in the upper atmosphere during the night. We can hear night programmes on the radio, not only because the ionisation produced by the sun is retained but because the atmosphere is ceaselessly bombarded by the tiniest meteors.

Other Uses of Radar

Such a delicate detector of foreign bodies, *i.e.*, of objects with electric properties different from the air, cannot fail to detect plenty of other things apart from meteors, ships and aircraft. It seems that a complete picture of the land-

scape is offered to the flying pilot on some types of receiving arrays, if only in the form of spots and lines on the fluorescent screen.

When in 1943 high-powered transmitters were introduced, even birds did not escape detection, and bird echoes became such a menace for British coast watching that radar operators had to be specially trained to distinguish them from echoes of military importance. Aircraft can usually be easily distinguished by their greater speed; not so naval craft. At long range the echo from a bird flying fully in the beam of a radio set can be equal in strength and speed to that of a ship. In fact, birds have given rise to several E-boat scares and to at least one invasion alarm. Even small birds in flocks can be a nuisance to operators.

Heavy rain is also a reflector.

Cloud Range Detection

A special kind of Radar which uses extremely short electromagnetic waves, namely those of the visible spectrum, has recently been applied to measure the distance of clouds. A very intense light flash of one microsecond duration is produced by a high voltage spark gap at the focus of a paraboloidal reflector. The beam is aimed at clouds and the reflected flashes are received by another paraboloidal mirror with a photocell in its focus. The task of the photocell is to rectify the waves (let only one direction pass), then they are amplified and displayed on the Cathode Ray Screen as usual. The distance of the reflected spot from the time base origin measures the range of the cloud.

The Moon

Epoch-making has become quite a phrase in modern engineering. It cannot be denied that another epoch was opened when for the first time radar came in contact with the Moon. Assumptions that echoes might be obtained from the moon were never taken seriously until Sir Edward

Appleton categorically stated that it was possible. Less than a year later his prophecy was fulfilled by the United States Signal Corps. Wireless experts assert that the conditions were of the utmost unsuitability. The equipment was an ordinary and old-fashioned Army Signal apparatus of such size that it could not be lifted. Therefore the experiments had to be performed when the moon had just risen and was standing on the horizon. That meant that the atmosphere did its worst to attenuate the signals. But nothing of all this prevented a full success, and on January 10, 1946, at 11.58 a.m., contact with the moon was achieved.

An interesting peculiarity of the moon echoes is that they manifest the phenomenon known as Doppler Effect. When a source of vibration moves towards the observer, he receives more vibrations per second than the source emits, so that, for example, the pitch of an approaching engine is higher than when it is at rest. As the moon moved with a relative velocity of 682 miles p.h. towards the earth, the reflected wave differed from the transmitted one by 227 cycles. The American experimenters had calculated this effect beforehand and tuned their receiving set accordingly. The fact that this particular frequency was received, as well as the time lag of 2.4 seconds between transmission and reception, were definite proof that the echo really came from the moon.

*Cave Science**

DR. MARIO PAVAN

THE study of caves in all their varied aspects is given the general name of spelæology.

Caves offer many different subjects of research to the student, and in the following pages we will glance briefly at their principal aspects, dwelling chiefly on the biological researches which have been the writer's particular concern.

No less worthy of consideration, however, is the explorative side of spelæology, which generally absorbs much energy and makes especial demands on the spelæologist. Indeed it requires a form of "Alpinism" whose chief characteristics are quite peculiar: it must be remembered that if the locality is new, a genuine *exploration* has to be made with all the unknown quantities and surprises inherent in unexplored territory, and with the disadvantage of being nearly always cut off from any kind of communication with the outside world. But if this were all it involved it would still be a relatively simple affair.

The exploration proper is only started after a long series of preliminaries ranging from locating the exact site of the cave to transporting the necessary equipment and making all the preparations. Lined up together on the ground for hunting and collecting are strange-looking bandoliers made like cartridge belts but provided with thick glass test-tubes, and in some cases, pairs of peculiar steel pincers or leather harness with hooks and strong rings; small cases containing compasses, goniometers, altimeters, thermometers, barometers, and hygrometers; helmets with odd-looking lamps and flexible tubing fixed on top, coils of rope, ladders of flexible steel cable, miners' lamps, accumulators for under-water lighting, overalls,

*Translated by Teresa Magnani.

floats, diving suits, field telephones, and other objects which are of less bulk but just as necessary and precious as the others. Then, if we are dealing with chasms, begins the longest, most fatiguing and most delicate of all the preparations, the one on which the outcome of the exploration largely depends—the putting together of the equipment used in descending the abysses. The actual exploration often presents extreme difficulties; climbing down over-hanging walls, wading through rivers or basins of ice-cold water, negotiating cascades or under-water 'siphons' or large semi-liquid deposits of bat guano, in which there is a risk of sinking and being swallowed up as in quick-sands.

All this often necessitates spending long periods underground, which may stretch into days on end, often in danger of an unexpected storm bringing down enormous torrents of water from which escape is difficult. On August 25th, 1925, this misfortune actually befell the unlucky expedition which was exploring the Bertarelli Abyss, when two men were swept away and dashed to pieces by the force of an unexpected flood, while the rest of the party escaped only with great difficulty after indescribable adventures.

Even greater complications and perils are encountered when exploring caves with vertical shafts, especially when these are the site of water phenomena.

Since lively interest has always been aroused by the great depth of some of the caves, a table is given below of the principal caves of the world arranged in order of depth. (Multiply by 3¼ times to convert metres to feet).

Cave	Depth	Locality
Spluga della Preta (Chasm of the Preta)	637 m.	Venetia, Italy.
Antro di Corchia	559 m.	Tuscany, Italy.
*Fledermaushöle (The Bat Cave)	557 m.	Styria, Austria.
Anou Boussouil	520 m.	Djurjura, Algeria.
Abisso di Verco	518 m.	Venezia Giulia, Italy.
Abisso di Montenero	500 m.	Venezia Giulia, Italy.

*not completely explored

Cave	Depth	Locality
Abisso Bertarelli	450 m.	Venezia Giulia, Italy.
*Henne Morte	446 m.	Haute Garonne, France
Abisso Frederic Prez	420 m.	Venezia Giulia, Italy.
Grotta Gugliemo	350 m.	Lombardy, Italy.
Pozzo di Trebiciano	329 m.	Venezia Giulia, Italy.
Tana dell' Uomo selvatico (The Wild Man's Den)	318 m.	Tuscany, Italy.
Il primo abisso del Colle Schirlenico	316 m.	Venezia Giulia, Italy.
Abisso Revel	316 m.	Tuscany, Italy.
Sarkotich	310 m.	Montenegro, Yugoslavia.
Grotta dei serpenti (The Serpents' Cave)	304 m.	Venezia Giulia, Italy.
Abime Martel	303 m.	Ariège, France.
Inghiottoio di Slivia (Gulf of Slivia)	303 m.	Venezia Giulia, Italy.

In France they have recently explored the Chevalier Cave (Dent de Crolles, between Grenoble and Chambéry) which has its own peculiar morphology, formed systematically so to speak by a tunnel with two mouths on opposite slopes of a mountain and with a series of wells rising vertically from the middle of the cave to the summit of the mountain. The distance from the outer mouth of the well to the lowest mouth of the tunnel is 658 metres.

Primitive human and animal life in the caves

Spelæology is indeed young; it has approached full status and taken its place as a serious science only in the final decades of the last century, mainly owing to the work of the Frenchman E. A. Martel. From its first beginnings it has owed a great deal to many other branches of science, and throughout its development has always maintained far-reaching and intimate connections with the other sciences.

A generalised interest in caves had already been arous of in the rare observer as far back as the Middle Ages, in we have few accounts of their explorations which valls worthy of record, apart from awe-struck reports of the inevitable "stone-forest" or the immensity of the years terranean regions. , where

*not completely explored

The palæontological deposits found in caves are of remarkable thickness—sometimes many feet—and often very rich in precious fossil substances. In the cave called Bucco dell' Orso (The Bear's Mouth) on Lake Como in Italy, for example, it has been calculated that there are at least three hundred skeletons of cave-bears!

The practical importance of subterranean hydrology

The importance of geological researches carried out in the caves is immediately obvious if we consider that one of the endeavours of the geologist is to compile maps of the earth's depths, proceeding by examination of the surface evidence.

The help which can be derived from direct investigation into the heart of the rock is, however, limited by the fact that the existence of caves is not a universal phenomenon but appears only in certain territories containing soluble rock (calcium carbonate). Caves in other regions are due to different causes possibly having nothing to do with the dissolution of calcareous rock under the action of water. They are rare and of negligible importance.

The geologist can, in any case, study all the problems inherent in the origin, development, and destiny of subterranean caverns; valuable discoveries can often be made of the circulation of underground water, with particular regard to its practical utilisation for hydroelectric power, irrigation, and the supply of water for the needs of man.

In connection with the supply of drinking water to the city of Trieste a lengthy investigation was made into the subterranean hydrology of the Carso, which was summarised in masterly fashion by E. Boegan in "The Timavo", a work published in the collection of "Memoranda of the Italian Institute of Spelæology (Postumia)". As a result the aqueduct serving Trieste uses water from the Randaccio spring, which is fed from the subterranean course of the Timavo—the largest and most typical underground river in Europe.

It is a widespread belief that underground water is free from impurities detrimental to the health of man, but although we may drink such water quite freely when it is distributed by modern aqueducts furnished with perfect sterilisation plants, there can be no such guarantee of safety when the water reaches us without undergoing the special purifying process. In actual fact water circulates through the strata of calcareous rock by means of cracks which are large enough to allow the passage of dangerous organic impurities along with the liquid. It is very rare for water flowing underground through the fissures in calcareous rock to be free from dangerous infection. Moreover people living on the mountains frequently get rid of the carcasses of animals which have died of sickness, and of offal and domestic refuse by tipping it all into the caves. The water infiltrating into the ground then soaks up these deposits of decaying matter and carries their poisons and disease-laden bacteria to the distant spring, which is not suspected of being anything but pure and wholesome. The annals of hygiene record numerous cases of epidemics and of wholesale and persistent poisoning whose origin has been traced to the deplorable practices described above. Sanitary legislation has therefore intervened in many countries and forbidden the throwing of any kind of rubbish whatever into the caves.

The Trou du Toro (Hole of the Bull) is a great gully 2,000 metres above sea-level in Spanish territory in the Maledetta massif of the Pyrenees, not far from the French frontier. The waters of the Rio Barranco are swallowed up and engulfed within it. The Spaniards had intended to divert the waters of this torrent before they disappear into the Trou du Toro, but there were some who suspected that the water spread underground and went to feed the Garonne in French territory, so that its diversion within Spanish territory might irremediably weaken the flow of the French river, with grave consequences for the farming population.

In 1938, after courageous and patient investigation, the French spelæologist N. Casteret succeeded in demonstrating scientifically the correctness of this thesis, and the international issue it raised was settled in favour of France, which, thanks to this expert student of caves, was able to safeguard the interests of the vast area irrigated by the Garonne.

In recent years the caves have been the site of important work in geodesy carried out with delicate and expensive scientific instruments, and a parallel study has been made of the singular meteorology of subterranean caverns, often with strange and unexpected results.

As cosmic radiation is studied in all the layers of the atmosphere, in the depths of the sea, and of fresh water, so too this study has very properly gone underground in order to find out the penetrative powers of these mysterious rays through different types of rock and under varying conditions. This kind of research will not of course remain isolated, but interesting possibilities are bound to develop of transferring its results from a purely theoretical field and applying them to the study of subterranean biology and to mining conditions.

Nor should we forget the important place taken by caves in the history of warfare, and above all the military and civil function they might assume in atomic warfare.

The United States are therefore carefully investigating the complex possibilities of the vast collection of galleries in the Mammoth Cave in Kentucky, an enormous natural cavern covering several miles.

Biospelæology: the study of cave vegetation

After this brief summary of some of the principal fields of study and possibilities of practical application in spelæology, we will pay somewhat closer attention to its biological aspect.

The flora of the caves has aroused scant interest in botanists, but they would in fact repay the most thorough

study, since there are many particular aspects worthy of investigation.

The higher plants are only found in the areas near the cave-mouth and those parts of the cave lighted either directly or by reflection from outside, which do not offer conditions of life differing excessively from the normal, and therefore give rise to no outstanding phenomena.

In the interior of the caves, where there is no light at all, the synthesis of the leaf-green pigment chlorophyll cannot occur, and in consequence the flora consists entirely of saprophytes which live on decaying organic matter, instead of relying on photosynthesis.

The fungi frequently found in caves, upon the usually plentiful organic vegetable or animal remains, often exhibit obvious cryptomorphic phenomena, *i.e.*, alterations in their usual structure which make it impossible to recognise the species to which they belong, for in the majority the reproductive organs rarely reach maturity, and so there can be no examination of the seeds, the usual determining factor in the identification of the different species. In some caves which have been adapted for tourists, and have electric light installed (which is turned on at intervals), species of the higher plants have succeeded—though with difficulty—in developing near these sources of intermittent light, making use of the little that they provide for photosynthesis. As an instance we may mention the existence of a new variety of moss (*Brachytegium velutinum* var. *spelæorum* Latzel) which developed near the "Grande Monte Calvario" in the Postumia Cave 1,700 metres from the entrance. This new moss formed a group with other vegetation in proximity to a 500 watt lamp which was turned on for about 500 hours a year (see plate 26).

In recent years attention has been drawn to the common phenomenon of the blackening of concretions in the Postumia Cave, and examination of the blackened patina has revealed the presence of micro-organisms in various stages of development.

I. Politi, who performed the preliminary work, suggests that the bacterial flora present on the concretions may be at least partly responsible for the blackening of the surface, since one suspects the presence of micro-organisms which take up iron oxide and manganese oxide, salts with the characteristic brown or black colour of the discoloration. The blackening of the walls of caves is often, however, due to different, non-biological causes, such as deposits from the dust-laden atmosphere, or particles of carbon from the combustion of the lights used by visitors, or from the fires of cave-dwellers in remote times. Apparently identical phenomena do not always spring from the same cause.

After this note on the study of vegetable biology we will look at some details of animal biology.

The fauna of the caves

If little work has been done on the flora of the caves the same cannot be said of the fauna, which has aroused and continues to arouse a most lively interest.

The first documentary evidence of cave fauna proper comes straight out of the prehistoric Magdalenian epoch, for it is an incising on a fragment of a bison's bone found in the "Trois Frères" cave at Ariège in the French Pyrenees.

The incision represents a cavernicolous insect (*Troglophilus*) which has now disappeared from the Pyrenees and from the whole of Western Europe, but which still exists in regions further East (Italy, the Balkans, Asia Minor). The unknown artist has transmitted in this fragment the most ancient evidence we possess of real cave fauna, which is attributed to an age many thousands of years past (Plate 28).

Prehistoric sculpture and drawings representing other animals (bears, lions, mammoths etc.) which go back to an epoch even more remote than that of the *Troglophilus* incising, do not possess the significance attributed to the latter, since though these animals were presumably the guests, even regular ones, of the caves, they were not properly at home in the subterranean regions.

Next we make a jump to G. B. Trissino who, in the first half of the sixteenth century, saw in the Covolo di Costozza in the Veneto, some little fresh-water crustaceans (*Niphargus*), referred to briefly by F. Leandro Alberti in his "Description of the whole of Italy" (see Fig. 1).

No really significant event occurred, however, until 1768 when the first description appeared of the "Proteus", that extraordinary amphibious newt belonging to the Cave of Istria, which became the most celebrated cavernicolous animal (see Plate 29).

In the last century the general flowering of science gave a notable impulse also to research on animal life in caves, which, it came to be realised, raised biological problems which were both new and highly interesting even from a general point of view. But while the few spelæologists concerned themselves with the new problems presented by the animal population of the caves, the biological aspect was somewhat neglected in favour of the systematic study of zoology. This played the most important part for a long time, which is understandable when it is considered that the caves, even in our own regions, were—and in part still are—virgin territory full of the most alluring new things. To cite only one example from one of the regions most studied by spelæologists—the province of Brescia in Northern Italy—in the past twenty years of biological research we have found at least fifty genera and species hitherto unknown to science!

At the beginning of this century, Racovitza made a survey of biospelæology and drew up a research programme based on the subjects which seemed to him the most important ones to investigate. His work aroused the attention of cave explorers and was a spur to the widening of our knowledge of the life of cavernicolous fauna.

When considering animals in relation to their cave environment, it should immediately be made clear that not all those found in caves are inseparable from them. For many years animals were in fact grouped in three categories

—those which lost their power of reproduction in a cave environment (troglosseni), those which retained this power and could still live in daylight (troglophili), and those which were compelled to spend their whole existence underground, from birth to death, and could not survive in daylight (troglobi). In 1944, the writer extended the scope of this division by pointing out that the troglosseni only arrive in caves by accident, whereas the troglophili actively seek out and prefer the underground dark.

Opinion is divided on the origin of the third group, the compulsory cave-dwellers. Some hold that in very remote times there was no proper cave fauna; that following the setting in of external climatic conditions unsuitable to many forms of animal life, these took refuge in the caves; and after a long period spent in their new surroundings they became completely dependent on the conditions of life underground and incapable of returning to the outside world.

Others suppose that through an actual organic tendency in certain animals these were to some extent forced to seek living conditions which only exist underground, and that the origin of the ties which they have contracted with the caves existed prior to their migration into that world.

One of the various other hypotheses finds the origin of the true troglobi in animals which came into the caves by chance and slowly settled in these surroundings, giving rise to all the troglobian fauna that we now know.

It is obvious that none of these hypotheses can be accepted or rejected in its entirety. Each one of them may correspond to some actual case, but none of them can be accepted outright as having a general validity.

When the distribution of cave animals is studied in further detail, it is found that underground water, like the land, shelters well-defined groups of animals. Even round the mouths of caves, there is a characteristic animal population made up of organisms which love damp, and seem to seek out this environment because the humidity varies less than

does that of the normal open world. Occasional caves which are excessively dry, or subject to passing seasons of dryness, often possess a fauna few in numbers and variety.

Light is not a decisive factor in determining the population of a cave. Many other considerations are of much greater importance: temperature, presence and degree of decomposition of vegetable and animal remains, constancy or renewal of the atmosphere, and the physical structure and chemical composition of the ground itself.

Some of the troglobi which love a high humidity can pass indifferently from land to water and back again. The writer has repeatedly seen this in different species of arthropods in caves in Northern Italy; for example Machilia, Trichoniscus, and an unidentified millipede. Sometimes, too, aquatic animals are found out of the water, for example a flat-worm (planarian), and an amphipod crustacean called Niphargus. This latter animal is often

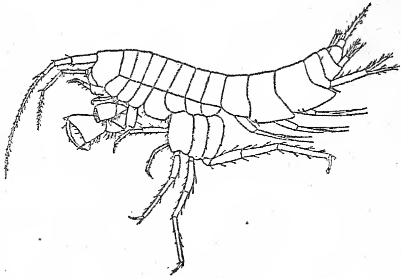


Figure 1

found in the waters of European caves, but where the cave is dry it digs out a little hole in clay with a tiny tunnel

running vertically to the surface. This shaft collects the minutest droplets of infiltrating water, and so keeps the Niphargus moist, however dry the cave as a whole may be. If its cell is opened inside the dry clay, a drop of water is often found. Facts of this sort suggest that given a saturated atmosphere, some cave animals do not distinguish clearly between air and water, and their respiratory processes must function equally well in both environments.

A problem of this kind is perhaps best studied in the laboratory in large experimental chambers in which the conditions of temperature, moisture, etc., can be controlled at will; or at the special underground laboratory fitted out fifteen years ago in the wonderful cave of Postumia in the province of Trieste. Unfortunately this laboratory was damaged by the German Army during the 1939-45 war, and it has recently come under Yugoslav administration; political unrest in the Trieste region makes its future uncertain.

This brief survey has touched on only a few of the problems of spelæology, but it has been enough to indicate that the subject has a definite contribution to make to geology, archæology and pre-history, and in biology to the problems of Evolution and adaptation.

Physics Front

A. W. HASLETT

Atom Postscript

A NUMBER of additions can now be made to the survey of atomic energy given in *Science News II*. One is the fact that thorium can be "transmuted" in an atomic pile into a new form of uranium—U.233—which like U.235 and plutonium is capable of being used as a "nuclear fuel". This is of importance, as well as interest, because there is rather more thorium in the world than uranium; and both India and Brazil, the two countries which are richest in supplies, are eminently capable of further development. There is, however, one very practical distinction between the utilisation of thorium and that of uranium as a source of atomic energy. It is that, whereas processes based on uranium are self-contained, processes based on thorium need small quantities of either plutonium or U.235 to start them off. And these are the only two materials from which atom bombs have so far been made.

A further point of interest about U.233—the new form of uranium—is that it is the starting point of a new radioactive series, which includes a hitherto unknown form of radium. The three existing series are those commonly associated with radium, actinium and thorium respectively. The starting points of the first two series are U.235 and U.238—the two commonest of the naturally occurring forms of uranium. Between them, these three series of radioactive elements include the whole of the known natural sources of radioactivity. They were laboriously worked out by Lord Rutherford and Professor Soddy in Canada early in the present century, and provided the foundation on which all modern knowledge of the atom was built up. It is therefore of rather special interest, scientifically, that

a fourth series should have been discovered, which is comparable in all respects with the other three, except that the radio-element from which it starts is not found in nature.

A natural first thought would be that the new form of radium which is included in this series should be of use in medicine. This is not, unfortunately, the case. It is neither long enough lived to be of practical use, nor is the radiation which it produces comparable with that from natural radium. This gap has, however, been filled by another discovery which also has only lately been published. It has been found that a radioactive form of cobalt can be made, merely by exposing normal cobalt to the intense neutron bombardment provided in an atomic pile; and this cobalt produces radiation which is very similar in quality to that of radium itself. It is, in fact, of somewhat more uniform character and medically, therefore, will probably prove more satisfactory to work with. Moreover, it can be made in quantities which could be large, compared with those in which radium is normally used; and, although it lacks the "permanence" of radium, rather more than four years has to go by before the strength of its radioactivity falls off by half.

The Photographic Plate in Research

Although attention tends inevitably to be focussed on the release of atomic energy and its consequences, nuclear physicists are more interested—aside from the social and international aspects—in fundamental research. Here, the main problems to be investigated are two. The first is to discover the nature of the forces which hold the nucleus of an atom together. This may seem curious when it has already been demonstrated that atoms can be induced to come part—and that on a wholly practical scale. None the less, it is true that, although there are ideas in plenty, these have not as yet been translated into any systematic and certain body of knowledge—or even into a single theory which makes sense. The second need, which ties

up with the first, is for more knowledge about the fundamental particles, already known or predicted in physical research.

For both these purposes, two main lines of research are available. One consists in the design and building of equipment in which particles can be accelerated to higher and still higher energies. This might be described as the bombardment approach. Its plans are measured in hundreds of thousands of pounds, and in millions of dollars —and, from the nature of the case, will take time to mature. The other main line of research is one in which relatively rapid progress is already being made. It is virtually without cost, and consists in the use of special photographic plates as so many miniature laboratories in which nuclear changes can be studied.

It is easiest to begin by assuming the result. Let us suppose that, for reasons unknown, the nucleus of an atom "explodes" at a point inside the sensitive layer of a photographic plate. As with any other explosion, a number of fragments will be produced which will fly apart, in different direction, and at different speeds. Being atomic particles, however, they will in most cases be electrically charged; and, as such, they will affect the photographic plate in the same way as would exposure to light. In other words, when the plate has been developed the tracks of particles will be found to have been recorded in it (see Plate 31).

As a research method, this was first systematically developed by Dr. C. F. Powell of the University of Bristol. It is less easy than it sounds, because the emulsion of the plate shrinks during developing and fixing—thus distorting the tracks—and the tracks are in any case distributed in three dimensions. None the less, Dr. Powell was able, over a period of years, to work out methods for recording accurately the lengths and directions of the original tracks, and for distinguishing between the different possible kinds of particles.

The principal new development has been the introduction

of special plates, in which the number of sensitive grains is greatly increased, and with the aid of these plates there has been a sudden outburst of research, using the methods which Dr. Powell earlier developed. The particular value of the method is that, pending the completion of the high-energy laboratory equipment already mentioned, cosmic radiation from outer space offers the only available source of particles of the highest energies for bombardment. Such particles are, however, comparatively few and far between, even at high altitudes in the earth's atmosphere—for example at a mountain-top laboratory, or during an aircraft flight. And the special advantage of the photographic plate is that it will record automatically all transmutations which may be produced within it during the period for which it is exposed. During the past six months, this has proved the most useful of all available research methods, and the same will probably remain true also during the next year.

Thirty Million Volt X-Rays

Meantime, progress on what may be called the electrical engineering front has been by no means negligible, and is likely within the near future to affect hospital practice, as well as nuclear research. The medical application arises from the fact that x-rays are produced whenever a beam of fast-moving electrons hits a solid target. This is the normal way in which x-rays are produced. What happens, in effect, is that the energy of movement which has been given to the electrons is released in the form of x-rays. It would be expected, therefore, that the higher the energy level to which the electrons are accelerated, the higher also will be the energy of the x-rays produced.

The first device for accelerating electrons to energies of ten million volts or above was the "betatron"—a magnetically operated "whirligig", due to Professor D. W. Kerst of the University of Illinois. Later, it was suggested both in Russia and the United States that, by a suitable combination of electrical and magnetic forces, electrons could be

accelerated to still higher energies. To one such device the name of "synchrotron" was given, and in autumn 1946 the Ministry of Supply's Telecommunications Research Establishment at Malvern attained the distinction of being the first laboratory in the world to make a "synchrotron" work. The important point was the purely practical one that, with the same bulk of equipment, and the same magnet, they could produce electrons of twice as great energy as with the earlier "betatron" system of working.

So far, the Malvern team has got up to 12 million volts with "synchrotron" working, and has designed a 30 million volt equipment, which is already complete except for the magnet. It will probably be already in operation by the time that these notes appear in print—and, by the sudden stopping of the electrons, it will produce x-rays of the same high voltage.

The reason that doctors are interested is that x-rays produce secondary radiation within the body. The effect becomes greater, as might be expected, as x-rays of higher energy are used; and it means that an appreciably greater dosage can be produced inside the body than at the surface. This is, of course, precisely what is wanted in deep x-ray treatment, since effective dosage can then be increased, without any corresponding risk of surface burns. At 30 million volts, it is expected that the greatest dosage will be at a depth of about two inches, with a comparatively slow falling off thereafter, and that the maximum intensity of radiation will be about four times that at the surface. There are a good many points which will need to be checked up, and for this reason a preliminary programme of physical and biological investigation is being carried out. The principle, however, appears already to have been established, and within the next year it may be expected that the first test installations at hospitals will already have been made. After that, it will be a question of medical research to decide how far up in voltage it is worth going; and of engineering research to determine the most economical

method of producing the necessary higher-energy electrons. Meantime, we know already that the "synchrotron" will do the job.

Cancer Yard-Stick

Cancer research has lately provided an interesting link between the methods of physics, chemistry and biology. This has taken the form of a new test by which it is suggested that the efficiency of any proposed cancer treatment can be investigated. The origin of the test lies, not in medicine itself, but in the science of genetics.

In brief, it has been known for some long period, that the chief vehicle for the conveyance of hereditary qualities from one generation to the next is provided by small bodies known as chromosomes, which can be made visible beneath the microscope within the nucleus of every living cell. These chromosomes are rod-shaped bodies, which are characteristic in size, number and shape for every form of life—and it is supposed that the "genes", the actual units of heredity, are located on them. The picture which has thus been obtained provides an explanation in general terms of the main facts of heredity. But it does not, in itself, account for the appearance of new "mutations"—of varieties, that is, which include qualities not directly derived from either parent. It was accordingly natural to look for possible external factors which might influence the normal course of heredity, by changing in some way either the chromosomes or the genes which they carry. One such agency was found in x-rays—although, under natural conditions, it may be cosmic radiation which does the job.

The effect of x-rays is, quite literally, to "knock the chromosomes about", and to do so with such violence, provided the correct dosage is used, as to interfere with the normal process of division by which the cells of the body reproduce themselves and are replenished. This, in turn, led to an explanation of the way in which x-rays, and for

that matter radiation from radium, come to be effective in the treatment of cancer. The answer, surprisingly at first sight, is that there is no specific effect against cancer at all. The only reason that cancer cells suffer more, under x-ray bombardment, than do normal cells, is that they multiply at a higher rate—and it is during the division process that the chromosomes are most vulnerable. The probability that a cancer cell will be "caught" at this stage —or, more accurately, at one of the stages associated with division—is accordingly greater than for a normal cell.

This suggested, as a further sequel, that any other form of attack against cancer might operate in the same way. It was guessed therefore that, from the observed effect on the chromosomes, the probable efficiency of any suggested method could be quickly gauged. The first attempts to apply this technique have lately been made by Dr. C. D. Darlington of the John Innes Horticultural Research Institution, and Dr. P. C. Koller of the Cancer Hospital research unit, and are thought to be quite promising. It should perhaps be emphasised, however, that the promise is as a method of investigation rather than as a treatment, which it is not. A number of chemical substances which appear to have some effect on particular forms of cancer are, as it happens, under investigation at the present time. This is where the chemical link-up comes in. But it is probably more important for the future that a new yard-stick has been found by which progress can be measured.

Structure of Wool

Another example in which progress in physical science has affected biology is provided by the structure of wool. The research weapon in this case has been the electron micro-scope, an article on which was included in *Science News 1*. It is also quite a good illustration of the way in which additional evidence may lead to the scrapping of one scientific picture in favour of another.

The original picture was based partly on the use of

x-rays to show repetitions of physical structure, and partly on the extent to which wool fibres expanded in water. It was due largely to Professor W. T. Astbury of Leeds, and so long as the available evidence was confined to these two lines of approach, it appeared both satisfying and satisfactory. In brief, it was thought that wool fibrils consisted of long chains composed of keratin molecules, and that the expansion of wool in water corresponded with the unfolding of these chains.

This was the simplest possible interpretation of the facts, as then known, and it was generally accepted as correct —until the electron microscope enabled wool fibrils to be directly photographed. Now that this has been done, workers under the Australian Council for Scientific and Industrial Research have been enabled to put forward a new picture which, although less simple and "pretty", is more likely to be correct.

They have found that wool fibres consist, not only of chain-like fibrils, but also of amorphous material which looks like so many loose beads thrown in a heap. In addition, the fibrils can be seen to be built up in sections, the size of which corresponds with that of the loose beads. The inference is that the basic unit is the bead, and that the fibrils consist of these beads, joined endwise together. It follows also that the physical theory of the stretching of wool, which had seemed so neat and cut-and-dried, will have to be reconsidered; and that the concertina metaphor, which has so often been used to describe it, will have to be abandoned. What does *not* follow is that there was anything the matter with Professor Astbury's earlier observation. Merely does it sometimes happen that a theory, which at the time appears the simplest, is proved later, and by further evidence, to be incorrect.

Microscope Progress

If the electron microscope is already proving its value, the optical microscope appears to be further from the end of

its useful life than some in the United States have been ready to suggest. Two quite different developments have lately been attracting attention, either of which separately would offer quite considerable possibilities. The first, which came from Germany during the war, was the technique known as "phase contrast" microscopy. This, essentially, is a way of showing up the structure of a colourless material—for example, living tissue—without having to introduce artificial colour in the form of a stain. The objection to staining is the obvious one that, even if the stain does not kill the organism or cells which it is being used to show up, it is impossible to be sure that it does not affect them. And the advantage of the "phase contrast" method is that, apart from the illumination which is inevitable with any form of microscopy, one does not have to "do anything" to the organism in order to observe it. Incidentally, the microscope itself remains, in essentials, as before. The innovation is simply that a new optical trick has been added to its working.

The same cannot be said of the reflecting microscope, as developed by Dr. C. W. Burch of the University of Bristol. Here the change which has been introduced is of a much more radical kind. In place of lenses, he has used a system of mirrors to obtain his magnification. One of his main reasons for doing so is that, whereas the properties of a lens depend on the wavelength of light with which it is being used, those of a mirror do not. This means that it should be possible, in theory, to use such a microscope with radiation which extends well into the ultra-violet region—and which is of too short a wavelength for the human eye to be able to see. The point here is that the shorter the wavelength of the radiation used, the more detail should it be possible to observe.

The hope, accordingly, is that with the type of mirror system introduced by Dr. Burch, it may be possible for the optical microscope to approach more nearly the limits of resolution already achieved by the electron microscope.

Nor will this hope, if realised, be a mere duplication. Whether an electron beam is used, or extreme ultra-violet radiation, some effect is likely to be produced on the object under examination. For this reason, it would be reassuring, at least, to have two independent methods available.

The main difficulties are practical. In order to produce a high-power reflecting microscope, it is necessary to work at least one, and preferably two, mirrors to special non-spherical shapes. Also, as with other optical equipment, this must be done to the highest possible accuracy. In describing lately the first such microscope which he has made, Dr. Burch stated that it was necessary to "have a great deal of patience, and preferably a little insomnia". In his second, which he expects to occupy him for two years, he proposes to "go to the limit". He will build it in collaboration with Mr. W. J. Bates, also of Bristol University.

"*Memory*" *in a Mercury Tube*

Although much has been published about the wonders of valve-operated calculating machines, it is only lately that the most interesting fact has been made known about the Automatic Computing Engine (A.C.E. for short) now under construction at the National Physical Laboratory, Teddington. This is the nature of the "memory" with which it is to be provided.

The question which comes first, however, is—why a memory at all? The simplest answer is that even a valve-operated machine does its calculations by stages, like any other performer in arithmetic; and, unless at every point it "knows" what to do next, much of the value of its speed of working is lost. It is much better that it should be "told" in advance what to do, and then left to get on with the job. And that implies that it must be able to store up, or "remember", the instructions given it. In addition, it is of obvious advantage that it should be able, without stopping in its work, to keep some record within itself of

intermediate answers, so that these as well as the final answer can be produced if required. Finally, if it is to "save itself trouble" by making use of any of the standard forms of mathematical table, it must be able, again, to store up and reproduce any information of this kind which is given to it.

The form of A.C.E.'s "memory" is dictated by its working treatment of numbers. These are represented, in a simple code system, by the presence or absence of electrical pulses at prescribed intervals of time, roughly every millionth of a second. Anything which the machine has to "remember" will take the same form—a series of pulses, punctuated by "not-pulses", at regular intervals. Since electrical changes travel, in any normal circuit, at speeds of the same order as that of light, the first requirement is clearly to find some way of slowing up their progress, and at the same time perpetuating the particular pattern of pulses which is to be preserved. This is done by providing a sort of endless chain circuit in one leg of which a delay in transmission is deliberately introduced. The delay-leg consists of a tube, about five feet long, which is filled with mercury, and down which the sequence of pulses is sent in the form of mechanical vibrations. Translation into this new form is achieved by a piezo-electric crystal, such as is used to provide the pick-up unit of a radiogram.

This, however, is only one leg of the memory circuit. At the far end of the mercury tube, a second crystal translates the pulses back again into electrical form. By this time, they are getting slightly distorted, although still identifiable as pulses or not-pulses, which is all that is required. They next pass to a "wash-and-brush-up" unit. Here they are inspected and identified, and passed out again in standard and correct shape to re-enter the mercury tube at the original end. In this way the pulse pattern can be kept circulating for as long as may be necessary, without any cumulative change either in strength or shape. The electrical part of the roundabout is covered practically

variation in the strength of gravity, when he is moved from one position to another over the sea bed. Ordinary diving bells have also been used for the same type of measurement, although these are naturally much more limited as to depth of operation.

The remaining method, like the gravity survey, is already well tried in normal land prospecting. This is the seismic survey, in which an explosion is used to initiate miniature earthquake waves. Seismographs, similar to those used in earthquake recording, are then employed to record the travel of the waves produced, which vary according to the local geology. In comparatively shallow water, the seismographs are lowered in water-proof casings to the seabed, and the "shot-hole" is cased from above the level of high tide to a sufficient depth to prevent leakage of sea water. Difficulties obviously increase with the depth. It is considered, however, that useful information can be obtained out to the hundred fathoms line, which is generally taken as marking the edge of the continental shelf.

Apart from submarine prospecting, it can be taken for granted that the magnetic method of air survey will be widely used in future, both over Antarctica and other regions which have so far been inadequately surveyed for minerals. It should perhaps be pointed out, however, that whatever method of survey is used, interpretation will always remain difficult, in the absence of fairly complete geological information—and that can only mean test drilling.

Another substantial improvement in geophysical prospecting has been in the ease and speed with which gravity readings of the highest accuracy can now be taken. The time needed for a single observation has been reduced from five hours to, literally, a minute, and the weight of the equipment necessary from more than two hundred pounds to less than fifty. Recent oil prospecting in Great Britain has been greatly speeded up as a result, and these advantages would clearly be of even greater value in difficult country.

Radio Lens Problem

An unusual problem has been presented to physicists by a form of radio transmitting aerial which was developed by the Admiralty Experimental Establishments during the war, but only lately shown in public. This particular set was designed for operation on 3.2 centimetres, and one of its objects was to look as little like a radio transmitter as possible. Removed from its box, the complete aerial assembly has the appearance of the side lamp of a car. And, in fact, the funnel part of the "lamp" turned out to be the mouthpiece out of which the waves were literally being poured. What was unusual, for a radio aerial, was that the "lamp" was fitted with a lens, made of polystyrene, a plastic material which has been widely used as an insulator. Even this would not perhaps have attracted much comment in these days, but for the fact that the diameter of this lens was no more than about 6 centimetres—the equivalent of about two wavelengths, on the frequency at which the transmitter had been operated. The oddity will be obvious to any physicist. According to all the rules, a lens should not act as such, unless its dimensions are large compared with the wavelength it is to refract.

None the less, say the Admiralty scientists, this particular lens really does behave as a lens should if of larger size; and the radio waves from the lamp really are beamed, as light waves would be, if they had been similarly focussed. The point is not, admittedly, of any major importance. It is none the less illuminating, in this age of the higher physics, that competent research men should find difficulty in explaining the working of so comparatively simple a piece of equipment.

Having said so much, it should perhaps be added that various other types of unorthodox aerial have been successfully explained. The one which was most used in practice was a tapered polystyrene rod about ten inches long (eight wavelengths). This produces as directional a beam as would quite an elaborate array of normal types—and the radiation

The soil is largely composed of mineral materials, organic matter, air and water. The particles of mineral matter differ greatly in size, from those that are coarse, such as gravel and sand, to those that are in a fine state of division such as silt and clay. The organic matter is variable in constitution, as it represents all stages of biological breakdown of plant material and all the products of metabolism and autolysis, due to soil organisms. This organic matter plays a fundamental part in developing the crumb structure of soil so important to soil fertility. The crumbs of soil exhibit pore spaces varying greatly in dimensions and occupied largely by water and air. Water is held in these pore spaces, and in the films of water at the soil-crumb surfaces biochemical changes of great importance to plant growth are continually taking place. These changes are influenced by the access of oxygen to the water films; if the access of oxygen is poor, as for example in waterlogged conditions, anaerobic changes occur whose biochemical characters are very different from those obtaining where oxygen access is unimpeded. The farmer refers to soils as varying in "tilth", a good "tilth" being defined as the optimum physical state for crop production. An example of a soil in good tilth is the black prairie soil of which the larger proportion is made up of granules from one to three millimetres in diameter. Such granules are stabilised by a coating of waxy organic matter. The soil has a high proportion of large pores and is readily permeable to air and water. Soil fertility is very much dependent on soil structure, for clearly plant roots, in order to develop most favourably, must have ready access to oxygen, water and other nutrients. The chemist has been greatly concerned with determining the availability in soils of essential plant nutrients such as compounds of nitrogen and phosphorus or of potassium ions and ions of many metals, which are partly held in combination by the mineral matter (especially the clay) of soil and partly by organic matter, which however is continually altering its character by decomposition. If

the soil is deficient in these nutrients, they must be supplied to ensure good crop production; or if through some character of the soil, nutrients are present but are not available to the plant, means must be found to make them available.

The microbiologist has been largely concerned with discovering the various types of organisms which exist in soil and the types of chemical changes which they bring about. These changes vary very greatly, for they involve the very important processes of transformation of the free nitrogen of the air into substances which nourish both microbe and plant and ultimately therefore all animal life; they involve processes affecting the states of combination of phosphorus and sulphur in soil and the manner in which iron or manganese or oxygen or carbon dioxide may take part in chemical reactions which influence the developments of micro-organisms and plants.

The study of the chemistry of all such changes accomplished by biological means under the conditions prevailing in soil forms the subject of soil biochemistry. The writer proposes in the ensuing brief article to examine a few aspects of, and some recent results obtained by investigations in, soil biochemistry.

General considerations

Soil may be considered from at least the two following points of view:

(1) It may be thought of pre-eminently as a medium for the growth of crops, all processes taking place within it being judged primarily from their importance in influencing crop production.

(2) It may be thought of as a complex biological system in which hosts of organisms are competing with each other, often for a limited supply of food. They exercise profound effects on each other's development and chemical activities, and establish between themselves a balance which is forever changing with every change in the physical and chemical environment of the soil. In such an equilibrium, the plant

plays an important part. The root cells form part of the complex cell system of the soil and the development of the plant becomes a function of the equilibrium condition set up in the soil.

This second point of view, in fact, embraces the first, but allows for a wider and more fundamental scope of investigation. The soil is studied, for its own sake, as a biological whole. Its metabolic events, under defined experimental conditions, may be investigated in a manner similar to those of any other complex system of cells, such as are presented by isolated animal and plant tissues. Progress in agricultural chemistry within the last hundred years has been due in the first place to the development of methods for determining the composition of plants and of soils, and in the second place to the recognition that soil micro-organisms are responsible for a great variety of highly important chemical processes taking place in the soil.

Liebig's views, faulty as some of them were, gave a great stimulus to soil investigation. They were based upon analytical studies and directly led to the work of Lawes and Gilbert at Rothamsted, which formed the foundation of the great fertiliser industries of to-day. Liebig's greatest handicap, however, was the fact that soil microbiology had not yet made its contribution to agricultural chemistry. The demonstration by Hellriegel and Wilfarth in 1886 that bacteria in soil infect legumes (plants of the bean, pea, clover family) forming nodules which, on the roots of the plant, are capable of fixing nitrogen,* followed seven years later by Winogradsky's discovery of a soil organism which can fix nitrogen independently of the plant, served to focus attention on soil micro-organisms as essential factors in soil chemistry.

The chemical aspects of soil microbiology have assumed increasing importance as the factors contributing to crop

* That is, of converting the inert nitrogen gas of the atmosphere into ammonia and nitrates, valuable fertiliser salts for the soil, and foodstuffs for the plant.

production have been unravelled. It is no exaggeration to state that there is now no aspect of soil microbiology without its bearing on the chemistry of the soil. This may be seen not only in the transformations that nitrogen undergoes in soil, but also in the changes that affect other elements essential to plant life: sulphur, phosphorus, iron or manganese. The breakdown of organic matter so essential for the development of the tilth or structure of a soil, the varied organic transformations that convert a chaos of complex materials in the soil into something rather less complicated, the production of carbon dioxide—which plays its vital part not only in the chemistry and physics of soil but in restoring to the atmosphere the carbon essential for plant life—all these are the direct results of biological processes in the soil. The bacteria, in view of their great preponderance in numbers and of their known great chemical activities, are held responsible for many of the biochemical changes taking place in the soil. In the transformation of organic matter, fungi also have activities which may, under certain conditions, exceed those of the bacteria.

The last twenty years have seen a great development in our knowledge of the biochemistry of bacteria and fungi. The isolation and investigation of these organisms in pure culture have not only resulted in increased knowledge of their specific chemical activities, but have also led to discoveries that have rapidly advanced fundamental biochemical knowledge. The studies of the processes of fermentation and of oxidative changes in yeasts and in bacteria have given a new insight into the mechanisms of breakdown of organic substances in the living cell, have thrown light on the mode of enzyme action and have led to the discovery of the parts played by a variety of vitamins in metabolic processes. Studies of soil bacteria and fungi have resulted in the preparation from them of substances whose antibiotic effects are of immense importance in medical therapy.

How do these results, obtained in pure culture and under

defined experimental conditions, important as they are in their fundamental character, help in the elucidation of processes taking place in soil?

The soil has an extensive microbiological population, made up of great numbers of species of bacteria and of genera of fungi, actinomycetes and algae as well as of numerous families of protozoa, nematodes and other invertebrates. Some of the soil organisms have relatively specific effects as in the fixation of nitrogen and the conversion of ammonia into nitrite, or of nitrite into nitrate, but frequently a large variety of organisms can attack a single substance. Thus the decomposition of cellulose can be brought about by many kinds of bacteria, having many different morphological and physiological characteristics, by fungi belonging to widely different genera and by many actinomycetes and other organisms. Proteins and fats may be attacked by complex soil populations. The manner of breakdown by isolated organisms in pure or even in mixed cultures of proteins, carbohydrates or fats may be followed in detail, but there can be no assurance that the same mode of breakdown occurs under soil conditions until experiments with soil have actually shown this to be so. The environmental conditions in soil are altogether different from those in the media in which metabolic studies of micro-organisms are usually studied.

Some conception of the enormous population of micro-organisms in soil is provided by the fact that there may be as many as 5,000,000,000 bacteria per gram of soil. This corresponds to a weight of over four tons of bacterial substances per acre of soil. The numbers of bacteria fluctuate very greatly, depending on availability of food supply, moisture, aeration conditions, temperature, hydrogen ion concentration of the soil and other factors. Direct counts under the microscope made by Conn in 1918 gave numbers of bacteria of the order of 250×10^6. Another method gave counts ranging from $1,280 \times 10^6$ to $2,160 \times 10^6$. Gray and Thornton improved the technique of bacterial

counts and obtained direct counts of the order of $4{,}000 \times 10^6$ bacteria in a gram of manured arable soil. Such figures were over a hundred times those obtained by the plating technique. Protozoa may reach figures of the order of 1,000,000 per gram of soil (amoebae 280,000, flagellates 770,000, ciliates 1,000, estimated on a neutral manured arable soil at Rothamsted). Algae may exceed 100,000 per gram of soil. Actinomycetes and fungi, both of which are difficult to estimate, may have a combined weight in the soil equal to that of the bacteria. According to Waksman and Starkey the numbers of actinomycetes range from a few thousands to many millions per gram of soil, whilst fungi may reach over 100,000 per gram.

In such a complex microbiological population there must exist numerous as yet unknown chemical interrelationships affecting metabolic behaviour and cell proliferation. Symbiotic associations take place and antibiotic developments occur. Growth factors and cell poisons are elaborated There is a constant disintegration of cells and a constant growth of new cells greatly influenced by, and possibly dependent upon, the breakdown products of the old. Cell adaptation occurs and the enzymic equipment of cells undergoes change in response to changes in their environment. The study of an individual species of organism remote from its normal environment in the soil can do no more than indicate its possible metabolic behaviour in the complicated biological system presented by soil. To the study of the biochemistry of soil *as a whole* we must ultimately turn for our data on its metabolic events.

Nitrogen Metabolism in Soil

Nitrogen Fixation

Let us now consider some aspects of nitrogen metabolism in soil. Boussingault's early experiments in 1837 made it clear that fixation of atmospheric nitrogen takes place during the development of legumes such as clover, peas,

and lucerne, whereas these fixations do not occur during growth of other crops, such as wheat. Liebig (1843, 1852), opposed to the view that free nitrogen of the air is assimilated by the plant, considered that atmospheric ammonia is primarily involved. Ville (1885) showed that this cannot be so. The classical work of Hellriegel and Wilfarth in 1886 cleared up a complicated situation. They showed that soil bacteria infect legumes, forming nodules which enable the plant to use atmospheric nitrogen. These bacteria, known as *Rhizobia*, were isolated in pure culture by Beijerinck. They were thought at first to be capable of fixing free nitrogen in the absence of the plant, but later work disproved this. Since there is no evidence that the host plant, in the absence of the rhizobia, can fix atmospheric nitrogen, it follows that some chemical interchange between the plant and the bacteria must take place *in vivo* and be largely responsible for nitrogen fixation. The excised nodules do not themselves take up nitrogen and the chemical association between nodule bacteria and plant, which results in nitrogen fixation, is unknown.

Much, however, is known of the biological aspects of this symbiosis or association between rhizobia and host plant. Details of these aspects are outside the scope of this article, but one important fact proper to the study of soil metabolism should be mentioned. When the seed of a legume germinates in a soil containing rhizobia, the latter are attracted to the region of the developing root hairs. There, a product of the metabolism of the rhizobia produces a deformation or "curling" of the root hairs. Such curling is induced by a specific chemical substance, for extracts of the bacteria are as effective as the living cells themselves. At the site of the deformation of the root hair the rhizobia invade the root tissue and proliferate, stimulating cell division in the neighbouring plant cells, and a nodule is formed.

There is evidence that the deformation of the root hair, essential as a preliminary to the invasion of the rhizobia, is

accomplished by indole-acetic acid, a common metabolic product of bacteria. It is known that indole-acetic acid and related plant "hormones" have but a transitory existence in soil, owing presumably to speedy decomposition by other bacteria. It follows therefore that metabolic conditions in the soil in the near neighbourhood of the germinating legume must be such as to enable a sufficiently high concentration of indole-acetic acid to accumulate to bring about the curling response in the root hairs. Though such a concentration may be small—of the order of one part in 100,000,000—a relatively high rate of production may be necessary to counteract the local destructive forces at work. It is known too that indole-acetic acid at low concentrations may be toxic to seed germination and that trypthopane in presence of soil bacteria will induce such toxicity. Thus metabolic conditions in soil will greatly influence seed germination.

Let us turn now to non-symbiotic nitrogen fixation. Winogradsky in 1893 found that an anaerobic soil organism, *Clostridium pastorianum*, will fix free nitrogen when supplied with the sugar glucose, the amount of nitrogen fixed being proportional to the amount of glucose broken down. The fixation of nitrogen is inhibited by the presence of ammonium salts and this inhibition may be counteracted by an increase in the glucose concentration. Thus the ratio of carbohydrate to combined nitrogen determines the rate of fixation of nitrogen. An interesting feature of this organism is that it loses its power of nitrogen fixation during prolonged cultivation on artificial media, but the power is restored by culture of the organism once again in soil. The soil factor responsible for the renewed ability of *Clostridium* to fix nitrogen is unknown.

Beijerinck in 1901 isolated from soil and mud two aerobic organisms capable of fixing atmospheric nitrogen. They are *Azotobacter chroococcum* (the more common form) and *Azotobacter agilis* (the motile variety). Unlike *Clostridium*, *Azotobacter* does not lose its power of fixing

nitrogen on prolonged culture on synthetic laboratory media. A striking fact concerning *Azotobacter* is that it requires for its metabolism the presence of traces of molybdenum or vanadium. A positive effect of Mo on the growth of the organism can be observed at a concentration of 1–3 parts in 10^9. Burk and Horner have found that molybdenum is not only required for the assimilation of free nitrogen, but is also necessary for the utilisation of combined nitrogen (in the form of asparagine or nitrate) by this organism. Tungsten will to some extent replace molybdenum. *Azotobacter* and *Clostridium* are apparently the most widely distributed non-symbiotic nitrogen-fixers in soil, and they are found also in salt and fresh water, often in association with algae.

In arid soils relatively poor in organic matter, micro-organisms form more than their usual proportion (about 5 per cent) of the organic matter, and this is chiefly due to the marked development of *Azotobacter* under the alkaline or saline conditions of such soils. It is stated that in the chestnut soils of south-east Russia, where almost the whole of the organic matter is in the form of micro-organisms, there are up to 900,000,000 *Azotobacter* cells per gram of soil.

The most important single factor influencing nitrogen fixation in soils is the presence of nitrate. Both with *Clostridium* and *Azotobacter* the presence of utilisable combined nitrogen diminishes the rate of nitrogen fixation, ammonium or nitrate being effective in this way. Inhibition of fixation by *Azotobacter* is complete in the presence of ammonium nitrogen at a concentration of 0.5 mg. N per 100 ml. The presence of nitrate or of ammonium salts in the soil also makes legumes resistant to attack by *Rhizobia*, fewer root hairs and nodules being formed. The net result is that, when excess combined nitrogen is available in the soil, little or no fixation of atmospheric nitrogen takes place. The presence of carbohydrates diminishes the effect due to the combined nitrogen.

Various factors in soil influence nitrogen fixation, amongst which may be mentioned moisture, hydrogen ion concentration, aeration, soil structure, temperature, and the addition of fertiliser salts (*e.g.* phosphates and calcium). Humus has a beneficial effect on *Azotobacter* growth, possibly owing to the iron contained in it, though traces of molybdenum present may be a responsible factor.

It has to be remembered that in soil there is an abundant flora of bacteria and fungi, other than the nitrogen-fixers; they will compete for the carbohydrates, which are the main sources of energy for *Azotobacter* and *Clostridium*. It has been estimated that, associated with the decomposition of 100 parts of available organic matter free from nitrogen, there may be fixed by the non-symbiotic bacteria about one part of nitrogen. This works out at only about eight pounds of nitrogen fixed per acre of soil receiving a liberal application of plant residues per year, though it has been stated that as much as 40 lb. of nitrogen per acre may become added to some soils annually as a result of the activities of the non-symbiotic nitrogen-fixers.

Ammonia Formation

It is known that the nitrogen compounds in plant residues are broken down in soil to form ammonia so long as the ratio of carbon to nitrogen in the organic matter does not greatly exceed 10. Proteins and other nitrogenous compounds are broken down in soil by a variety of organisms, the ultimate nitrogenous end-product being ammonia. Whether the ammonia appears or not depends on the rate of proliferation of other organisms in the soil requiring the ammonia nitrogen for their own synthetic operations. If there is ample utilisable non-nitrogenous material, such as carbohydrates, present, the ammonia nitrogen will not appear, as it is entirely used for building up fresh bacterial or fungal matter. Proteins being rich in nitrogen yield ammonia in relatively large amounts. The production of ammonia in soil was long attributed to the large sporing

groups *B. mycoides* and *B. subtilis*. It is now known that non-sporing organisms of the *Ps. fluorescens* group are active ammonia formers.

It is evident that many organisms may be involved in ammonia formation, the mechanism of which in most instances is unknown. If the proteins are broken down to amino-acids, these may yield ammonia by the action of oxidase enzymes in the organisms, increasing knowledge of which is now being derived from the study of animal tissues. Little is known, however, of the modes of breakdown of nitrogenous organic matter in soil and there is here an interesting and fruitful line of investigation.

Nitrification

This important metabolic process of soil whereby ammonia and organic nitrogenous material are converted finally to nitrate was shown by Schloessing and Muntz, from a study of the purification of sewage water by land filters, to be a biological process. Warington showed that soil nitrification is inhibited by application of chloroform and carbon disulphide and described two sets of organisms apparently involved in the process, one which converted ammonia to nitrite and the other nitrite to nitrate. In 1890 Winogradsky isolated the responsible organisms. Warington made it clear that the final fate of nitrogen in the soil is the production of nitrate, which thereby becomes the main source of nitrogen for the plant. Progress since the end of last century has been extraordinarily slow. Stevens and Withers in 1910 showed that nitrification in the soil differs in at least one important aspect from that in the artificial media first elaborated by Winogradsky. They demonstrated that nitrification in soil is inhibited far less by the presence of added organic matter than in laboratory media. They had already shown that nitrification of cotton-seed meal and of ammonium sulphate is more rapid under soil conditions than in culture media. In 1915 Allen and Bonazzi showed that soil, even ignited soil, is superior to

sand in supporting nitrification, and a number of workers (Albrecht and McCalla, Conn, and Conn and ZoBell) claim that the presence of colloids in culture media influences bacterial behaviour.

Meyerhof's extensive studies on the metabolism of *Nitrosomonas* and *Nitrobacter*, the organisms respectively responsible for the conversion of ammonia to nitrite and of nitrite to nitrate, have thrown much light on their behaviour in artificial media. Ignorance, however, of the details of nitrification processes in soil is largely due to the dearth of suitable experimental work on the soil itself. There is an immense literature on field and pot experiments showing the nature of the end products after application of organic nitrogenous matter. This work is of high practical importance, but it helps little towards elucidating the mechanism of nitrification in soil. Attempts have been made to correlate soil nitrification with soil fertility, but the general relations between the results obtained with culture media and those obtained with soil are obscure. Albrecht and McCalla state that "the complexity of sand, silt and clay mixture as soil prohibits an accuracy great enough to encompass all the various chemical aspects of so delicate a process as nitrification."

It has long been apparent that there is need for a quantitative study of nitrification processes in soil, and indeed there is need for a detailed study of all metabolic processes known to proceed in soil, under the conditions actually obtaining there.

For an accurate study of such metabolic events it is essential to have an apparatus which will ensure standardisation of soilconditions andthereforereproducibility of results. Many observations have shown how difficult it is to secure reproducibility of results without the most careful control of conditions. There are difficulties due to the heterogeneity of the soil, to variations in the water content, to variations in oxygen penetration in various parts of the soil, to alterations due to its handling for analytical purposes.

A fresh method of approach has been made by Lees and the writer by devising an apparatus whereby a column of soil (in the form of sieved air-dried crumbs) is perfused with oxygenated, or aerated, fluid by a circulatory technique. This enables the same soil solution to percolate through the soil for an indefinite period. The underlying idea is to treat the soil as though it were an intact organ and to perfuse fluid through it as though it were an isolated living heart or kidney in the preparations familiar to the physiologist. The soil perfusate is adequately mixed and aerated and the perfusion is intermittent, so that waterlogging of the soil does not take place. The process is continuous and may be maintained for an indefinite period. The substance whose metabolism in the soil is being investigated is dissolved in the perfusion fluid, or mixed with the column of soil.

This technique for investigating soil metabolism has many advantages including the following:—

(1) The water content of the soil is kept constant and the water is homogeneously distributed in the soil throughout the entire experiment.

(2) Maximal aeration of the soil is effected.

(3) The soil itself is not handled in any way during the experiment, analysis being confined to the constituents of the perfusate. The soil may be examined after any arbitrary time for analysis of ions adsorbed onto the soil.

(4) Substances such as biological poisons or inhibitors can be added to the soil solution during the course of an experiment and at any period corresponding to a known metabolic activity of the soil.

(5) Gases entering the apparatus can be controlled; metabolic events in atmospheres of oxygen, or nitrogen, or carbon dioxide or mixtures of these gases may be studied.

(6) The soil solution can be replaced at any given time by the solution of any metabolite of which the transformations are the subject of study.

The velocities of metabolic events in the soil may be

accurately studied by this technique. The soil is, in fact, treated as a biological whole, every effort being made to ensure constancy of the environment in which the soil is exercising its metabolic functions.

Using this apparatus it was easy for us to show that the transformation of ammonia into nitrate is biological. This was indicated from the speed of the transformation, which followed the logarithmic "auto-catalytic" curve typical of bacterial growth, and from the effects of biological poisons.

Further experiments gave rise to the conclusion that the rate of nitrification of a given quantity of ammonium sulphate is a function of the degree to which the ammonium ions are adsorbed onto or combined in the soil, on its base-exchange complexes. The greater the amount of adsorption, the faster was the nitrification. This was shown by comparing the rates of nitrification of soils having different amounts of ammonia adsorbed upon them. The only tenable explanation of the results was that the adsorbed ammonium ions are those which are preferentially nitrified by the soil organisms. This led to the prediction that the addition of sterile soils to a nitrifying soil would increase its rate of nitrification in proportion to the base-exchange capacities of the added soils; this prediction was verified.

The interpretation of these results is that the nitrifying bacteria grow on the surface of the soil crumbs at the sites where ammonia is held in base-exchange combinations, and proliferate at the expense of such adsorbed ammonium cations. The rate of proliferation is proportional, therefore, to the area of soil surface on which ammonium ions are adsorbed or combined and is thus a function of the base-exchange capacity of the soil.

The fact that proliferation of the nitrifying organism takes place only at those specific sites of the soil surface where ammonium ions are adsorbed leads to the conclusion that when all these sites of the surface have been occupied, further growth of the organisms will not occur except to replace cells which have died and disintegrated. Remarkably

few living nitrifying cells enter into the soil solution. This leads to the conception of a bacteria-saturated soil; that is to say a soil where the area of growth is limited and cannot be extended owing to full occupancy of available sites for proliferation. Such a soil should break down substrates, used only by the organisms which enrich the soil, at constant rates, and should not show the familiar logarithmic course of metabolism which obtains during proliferation. A bacteria-saturated soil has many of the properties of a biological catalyst. It decomposes a substrate at a constant rate which shows no initial lag period, until the amount of substrate falls below a certain concentration, after which further decomposition seems to follow the unimolecular law.

A very important use may be made of bacteria-saturated soils. They may be made to yield information as to whether any given substance is broken down by the cells which saturate the soil. For example it may be asked whether methylamine which is quickly nitrified by soil organisms is converted into nitrate by nitrifying organisms alone or whether additional organisms are required for a preliminary attack on the methylamine. To answer this question a soil is prepared which is saturated with the bacteria which convert ammonium ions into nitrate. With such a soil nitrate formation is perfectly regular and steady in time. This bacteria-enriched soil is now washed with water to free it from nitrates and it is perfused with methylamine. If the nitrifying bacteria themselves convert methylamine into nitrate the rate of conversion will be constant with no initial delay period. If they cannot bring about this conversion and if another set of organisms must develop prior to nitrification, there will take place an initial lag period followed by the familiar logarithmic increasingly speedy course of nitrification. The experiment proves conclusively that, in the soil, nitrifying organisms cannot themselves convert methylamine into nitrate. This technique is now being used for exploring the abilities of

nitrifying organisms to break down a variety of nitrogenous substances.

Attention may now be given to the remarkable bacteriostatic* effects of potassium chlorate on the organisms that convert nitrites into nitrates. Quite small concentration of potassium or sodium chlorate (*e.g.*, $M/10^6$, or about 1 in ten thousand), have the power of preventing the development of *Nitrobacter*, whilst that of *Nitrosomonas* proceeds undiminished. The result is that when nitrogenous substances are nitrified in soil in the presence of small quantities of chlorates, nitrites but not nitrates accumulate.

Potassium chlorate acts as a typical bacteriostatic substance. This may be shown by adding it to a soil already enriched with nitrite-oxidising organisms. The presence of chlorate does not poison, or interfere with, the oxidation of nitrite to nitrate. With a *bacteria-enriched soil* the conversion of nitrite into nitrate proceeds at a constant rate uninfluenced by concentrations of chlorate which inhibit proliferation of the organisms involved. Further investigation of the phenomenon of chlorate bacteriostasis indicates that chlorate has the effect of greatly increasing the initial delay period shown by *Nitrobacter* in the course of its proliferation. Ultimately even in the presence of chlorates, so long as these are not in too high a concentration, nitrite is attacked and oxidised. Further work has revealed the fact that chlorate bacteriostasis may be neutralised by the actual presence of nitrates, which appear to act in a specific manner. Explanations for these phenomena are still lacking.

Manganese Metabolism

Let us now consider an entirely different aspect of soil metabolism. It is known that in addition to nitrogen, phosphorus, sulphur, calcium, magnesium, potassium and iron, which the plant must obtain from the soil, the elements manganese, copper, boron, and zinc are also necessary for

* *i.e.*, it prevents the organisms from multiplying, but does not kill them.

healthy plant growth and even such elements as cobalt, molybdenum, tungsten, vanadium and selenium are reputed to have beneficial effects on certain species of plants. The amounts of some of these elements required for the healthy nutrition of the plant may be exceedingly small. One part of boron in twelve millions in a nutrient solution in which beans are grown will suffice to maintain them in good health. A concentration of one part of molybdenum in a hundred millions in a nutrient solution will ensure vigorous growth to the tomato plant. Deficiencies of these substances, as well as of major elements such as nitrogen, phosphorus or potash, lead to a great variety of plant diseases.

Now it does not follow that if an essential element is present in the soil it is necessarily *available* to the plant.

Manganese is essential for healthy plant life. Its deficiency in soil (and soils rich in organic matter and lime are prone to this deficiency), leads to plant diseases such as grey speck of oats or marsh spot of peas. Its deficiency may cause a substantial reduction in the yield of a potato crop or complete failure of an oat crop. But many of these deficient soils—as diagnosed by inspection and analysis of the crop—often contain relatively large quantities of manganese. Thus it is apparent that manganese exists in the soil in at least two forms, of which only one is available for the plant. So far as is known it is only the base exchangeable manganese—manganese cations,* most probably wholly in the bivalent form—which is available for the plant. Manganese dioxide clearly is not available for a plant, for this substance is known often to be present in "manganese deficient" soils.

The question now arises as to why certain soils containing ample quantities of manganese are "manganese deficient"

* Manganese atoms exist in solution as electrically charged particles, each carrying two units of positive charge (bivalent), Mn^{++}, or three Mn^{+++}, or even four Mn^{++++}. Increase of the positive charge is termed an oxidation.

and why other soils containing much less manganese are "manganese available". This question is intimately connected with the metabolic transformations which manganese undergoes in soil.

It has been shown by Mann and the writer that when manganous (Mn^{++}) sulphate is perfused through soil, oxidation of the manganese takes place. This oxidation in neutral or slightly alkaline soils (pH 6.0 – 7.9) is almost entirely accomplished by the micro-organisms present. This is shown by the following facts:—

(a) The rate of oxidation of manganese in soil at 70°F. follows the logarithmic or autocatalytic course expected if proliferating organisms are responsible for the oxidation.

(b) The rate of oxidation in soil is greatest at a certain concentration of the manganese, above which the rate falls.

(c) Heating a soil for two hours at 80°C. or one hour at 100°C. eliminates its capacity to oxidise manganese.

(d) A number of biological poisons retard manganese oxidation.

It is possible in fact to discriminate between biological and non-biological oxidation of manganese in soils by means of a biological poison such as sodium azide, which does not affect the purely chemical oxidation. Non-biological oxidations of manganese take place to a marked extent only in alkaline soils such as those that have been highly limed. It is well known that soil contains organisms capable of oxidising bivalent manganese. This has been shown by Beijerinck, Gerretsen and Nachlan, but it was not known, until the present work was carried out, how far manganese oxidation in soil is accomplished by micro-organisms. The usual view in the past has been that manbanese largely undergoes autoxidation in the soil; that is, that it changes spontaneously in the presence of air.

Not only is bivalent manganese oxidised to states of higher valency by soil micro-organisms, but similar agencies are partly responsible for the reduction of ter-and quadrivalent manganese to the bivalent form.

Many substances to be found in soil will reduce manganese dioxide, for example, polyphenols and sulphydryl compounds and ferrous ions. But living cells will accomplish the reduction in presence of traces of "carriers", such as pyocyanine, a pigment normally formed by *B. pyocyaneus*, a soil organism. Many bacteria in presence of certain organic substances, which they activate, reduce a molecule such as pyocyanine to its colourless leuco form, which in turn reduces manganese dioxide to its original form, manganous ions being produced. Thus the pigment acts as a reduction carrier between the organism and the manganese dioxide.

As might be expected from these facts, the addition of glucose and other carbohydrates to a soil containing manganese dioxide brings about an increased production of bivalent manganese ions, for the glucose stimulates the growth of organisms which, in presence of glucose and the natural carriers in the soil, reduce the higher valency states of manganese. This is shown in Figure 2, from which it is clear that the glucose perfusion of a soil increases bivalent

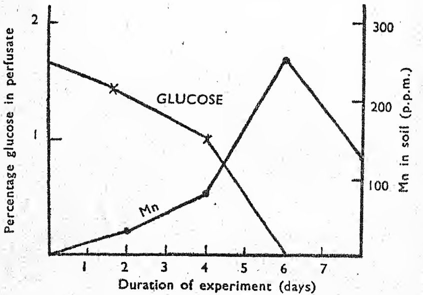


Figure 2

manganese concentration in proportion to the amount of glucose present. If the experiment is modified so as to decrease the moisture present, the effect of the glucose under aerobic conditions in stimulating bivalent manganese formation is not so apparent. This is simply due, however, to the experimental conditions favouring a relatively higher rate of biological manganese oxidation.

These facts point conclusively to the existence in soil of a cycle of biological changes involving manganese oxidation and reduction. The kinetics of this cycle determines the amount of bivalent manganese available in soil for plant nutrition at any moment.

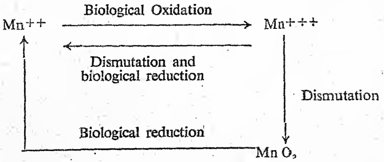
My colleagues, Dr. Mann and Dr. Dion, have shown that the first product of biological oxidation of bivalent manganese in soil is the tervalent ion ($Mn^{++} \longrightarrow Mn^{+++}$).

Meyer and Nerlich found in 1921 that manganic hydroxide, $Mn(OH)_3$, is stable in alkaline solution, but decomposes in acid solution to give a mixture of bivalent manganese and manganese dioxide, thus:

$$2\ Mn(OH)_3 = MnO + MnO_2 + 3\ H_2O$$

This dismutation goes on in soil; so that it is clear that, when biological oxidation of bivalent manganese takes place in neutral or slightly acid soils, tervalent manganese is formed and dismutes forming manganese dioxide and bivalent manganese which undergoes biological oxidation once more.

The manganese cycle in soil under aerobic conditions may be pictured as follows:



Under anaerobic conditions or in presence of a respiratory poison such as sodium azide, the equilibrium shifts markedly to the bivalent manganese side on the left and it will be expected that ultimately all the manganese will appear in that form.

Another factor that should also be considered is the immobilisation of manganese cations as insoluble manganese carbonate or as complexes in inorganic or organic materials.

In the complicated conditions occurring in the field, the equilibrium concentration of bivalent manganese will vary greatly according to the conditions that govern the bacterial population and its reducing or oxidising properties, *e.g.*, moisture, aeration, organic matter, temperature and hydrogen ion concentration.

It must be obvious that the manganese deficiency problem involves many factors bearing on the manganese cycle and will not be cleared up until much more work has been carried out on the kinetics of this cycle.

Carbon dioxide and soil metabolism

Let us turn now finally to a brief consideration of another molecule of great importance in soil metabolism—carbon dioxide. It is well known that the potentialities of the soil for the digestion or oxidation of organic compounds are immense. It may be regarded as the most effective digestive system known. Not only are cellulose, proteins and fats broken down in soil by a variety of organisms but more resistant materials such as lignins undergo change, probably into even more resistant substances such as humic acids. Clearly oxidation of the total carbon deposited on the soil by decaying plants and all forms of animal life must eventually take place, otherwise there would be a gradual accumulation of dead organic matter piling up on the earth's surface. The organic matter of a soil receiving no added material becomes gradually depleted as is shown by the fact that about 30 mg. of carbon dioxide may be

produced per kilogram of soil of average fertility each day for about 200 days of the year. Formation of about seven tons of carbon dioxide for an acre of soil per year may take place.

The capacity of the soil to produce micro-organisms that will decompose organic matter seems to have no limitation. Organisms have been found capable of oxidising and utilising substances such as phenol (carbolic acid), benzene, toluene, xylene and many polyphenols. Gray and Thornton have found several kinds of bacteria that can oxidise the cresols, toluene and naphthalene. Keratin* is decomposed by strains of *Actinomycetes*. Johnson and his colleagues have isolated from the soil around a petrol-pump organisms which oxidise n-pentane, n-hexane, n-octane, n-nonane and attack lubricating and paraffin oils.

The amount of carbon dioxide evolved must be dependent on the respiration of the soil; it is derived partly from the activities of the micro-organisms present and partly from the metabolism of plant roots. The air of the soil is considerably richer in carbon dioxide than the normal atmosphere above, and the constant evolution of the gas by enriching the atmosphere at and above the soil level forms a definite stimulus to plant assimilation and growth. This is apparent from the work of Lundegaardh and many others. The formation of carbon dioxide is important also in bringing into solution relatively insoluble soil minerals containing phosphorus, potassium, calcium and magnesium.

Attention, however, should be drawn to the fact that carbon dioxide is important in the assimilatory activities of bacteria themselves. It yields the only form of carbon that can be utilised by the immensely important autotrophic organisms of soil. It plays an active part in the metabolism of heterotrophic organisms. (Autotrophs manage to exist on an inorganic source of nitrogen and carbon dioxide only; heterotrophs require their carbon in the form of organic matter. Wood and Werkman first pointed out that pyruvic

* The protein of hair, skin, hoof and horn.

acid, a substance occupying a key position in metabolic changes of the living cell, condenses with carbon dioxide in bacterial cells to form oxalo-acetic acid, which then undergoes a series of biochemical transformations. The carbon dioxide is thus brought into the assimilatory activities of the heterotrophic organisms responsible for this change. Using the stable isotope of Carbon C^{13} it has been found that the labelled carbon of carbon dioxide is present in the carboxyl groups of succinic acid synthesised by the bacteria.

$$CO_2+HCH_2.CO.COOH \rightarrow HOOC.CH_2.CO.COOH.$$

The central position taken by pyruvic and oxalo-acetic acids in many metabolic changes occurring in bacteria and moulds implies that free carbon dioxide is assimilated by these organisms and is ultimately built up into their substance.

Wieringa showed that spore-forming organisms from mud, belonging to the *Clostridium* group, can convert carbon dioxide and molecular hydrogen quantitatively into acetic acid, an observation confirmed by Barker, Ruben and Beck, using the labelled carbon technique.

It is known that carbon dioxide can be reduced by certain organisms to methane, and an elegant experiment of Barker and his colleagues has shown that when the *Methanosarcina methanica* decomposes methyl alcohol in the presence of radio-active carbon dioxide, the resulting methane is radio-active. A part of the cell material obtained during the growth of a methane-producing organism is shown, by making use of radio-active carbon (in the carbon dioxide), to be derived from the carbon dioxide.

There are no observations yet on the possible part played by carbon dioxide of soil in the nutrition and development of heterotrophic organisms proliferating there, but it is clear from the facts given that it must be playing a highly important part in the general metabolic processes of soil.

It is not possible, in so brief an article, even to mention highly interesting aspects of sulphur, phosphorus, iron and

hydrogen metabolism in the soil or to comment upon the valuable work being carried out on the elaboration of antibiotics by actinomycetes and fungi, which must greatly affect the biological equilibrium in soil. Nor can we write about the important symbiotic associations in soil, such as the mycorrhiza which offer such interesting biochemical problems. It must be clear that soil biochemistry is a wonderfully fertile field for investigations of the chemical interrelationships of micro-organisms and for the study of complex biological systems in every way as interesting as the more familiar cell systems of animal and plant tissues.

Medical Front

JOHN ENOGAT

The Common Cold

ON another page (Plates 1–16) we show scenes from a unique experiment now being conducted at Harvard hospital, Salisbury, jointly by the Ministry of Health and the Medical Research Council, to investigate the nature of the common cold. It is a long-term experiment on batches of human volunteers, designed not to try out cold "cures", or even to find a cure, but to gain more scientific knowledge about this irritating and wasteful disease, which is reckoned to lose us forty million man-days of work annually. Only by slow, fundamental, painstaking work can we hope eventually to solve this problem: the cure will only become available when we know a great deal about the virus which is responsible.

Viruses are infectious germs, usually very much smaller than bacteria, from which they can be separated by filtration through collodion filters. They cannot be seen through ordinary microscopes, nor can they be grown in the tubes of broth or dishes of jelly on which the bacteria of diphtheria or scarlet fever or typhoid are cultivated in the hospital laboratory. They will only grow inside living cells; usually, that is to say, inside the common experimental animals (mice, rabbits, guinea pigs, ferrets, monkeys) and sometimes inside living eggs. This makes it more difficult to study them. In the case of the common cold virus the position is worse still since the only living thing where it will grow is apparently Man himself. All the laboratory animals are useless. Even eggs have so far not been successfully infected. One of the first tasks facing the Cold Research team at Salisbury and the National Institute for Medical Research, Hampstead, is to find something more

convenient than a human volunteer in which to grow the virus. A report put out by A. R. Dochez in 1931 that chimpanzees caught the cold has now been amply disproved, and so far the present team has apparently drawn a blank.

They reported a few of their results from the first ten months' work to the Royal Society of Medicine in May of this year. Throat and nose washings collected from people with colds on the first or second day of their illness were centrifuged to remove mucus and then filtered through collodion membranes in which the holes were on the average only seven-ten-thousandths of a millimetre in diameter. This is small enough to hold back all bacteria, but lets the virus through. The filtrate can then be used neat, or after various treatments, to infect volunteers. For instance it was diluted with water, and shown to be still infective when 100 times weaker than usual. It was stored at various temperatures and shown to be still infective after 3 days at 4° C, or after 27 days in a refrigerator at —10° C, or after more than four and a half months at —76° C. By doing further filtrations through membranes with still smaller holes, until one was found with pores too small to let even the virus through, an estimate of the size of the germ was obtained as something between 0.3 and 1.5 ten-thousandths of a millimetre across, a distance corresponding to about 200 atoms side by side.

On the more clinical medical side, the results show that most people go down with a cold on the second or third day after infection, while a few start in 24 hours or delay for almost a week. The cause of this variability is not known. An even more striking variability is shown in the liability of the volunteers to infection. Of 64 people receiving a dose of the germ, no less than 25 (about three-eighths) failed to catch cold at all, and a further 11 only had mild or very doubtful colds, so that less than half of them were really susceptible. This immunity apparently bore no relation to colds in the previous six months, for some volunteers in the immune groups of 25 had had

them then, and some had not. If we only knew the nature of this immunity we might be able to stimulate people's resistance and ward off colds altogether. In spite of patent medicine advertisements to the contrary this cannot yet be done, and it is still a matter for research.

Penicillin and the sulphonamides are useless against colds, and in fact no drugs are yet known to fight any virus infection. The difficulty perhaps arises from the germ's position inside the living cell, where drugs cannot enter, or if they do, only at the cost of killing the patient as well as the disease. In 1943 there was a report that a substance produced by a mould, penicillium patulum, and called patulin had proved powerful in treating colds. Further tests on more people showed no significant improvement, however, and tests of this kind are difficult to carry out for a disease which usually only lasts a few days anyhow. It means very careful statistical comparison of treated and untreated patients, and when this was done on large numbers, patulin failed.

Without Comment

According to Mr. Glenvil Hall, Britain will spend sixty-eight million pounds of the taxpayers' money on scientific research in the year 1947-8. This will be divided up for the different sciences broadly in the following way:

Medical research	£698,000 (1% of the total)
Agriculture and fisheries	£2,070,000
Industrial research ..	£14,780,000
Military research	£49,731,000 (73% of the total)

Flesh on Fire?

A cut which gets infected becomes red, hot, painful, and swollen; a boil is a similar infected swelling. How do you regard this? Is the inflammation caused by the germs at work, and should the doctor's aim to be to suppress the signs of enemy infiltration? Or is the inflammation a manifestation of a vigorous body fighting back, and therefore

to be encouraged and promoted? During the centuries medical opinion has swung back and forth from one view to the other. Before bacteria were known, inflammation in illness was welcomed as a sign of the strong patient. Plenty of pus oozing from a wound was a laudable state of affairs, just what the surgeon wanted to see, because experience had taught him (in the old days before antiseptics and penicillin) that the weak and old who showed little signs of inflammation usually soon died. Or if this did not happen the patient was found to stay ill for a long time, with recurrent fever, and slow wasting, while pus accumulated somewhere, dammed up and unable to escape in the usual way from a wound. So a steady flow of the sticky greenish or yellowish white fluid showed the situation was under control.

Then with the realisation that bacteria caused diseases, and the invention of antiseptics, and an aseptic technique in surgery, pus became a sign of invading germs, something to be stamped upon and cleared out, sometimes an indication of bad operational skill, always anathema. And so medical opinion swung the other way, and pus was laudable no more.

Now we are entering an altogether new phase in opinion on inflammation, a return to the older view that inflammation is a natural reaction of a healthy body, and as such to be approved and encouraged, but a view based on a great deal more knowledge than any hitherto, and therefore held with much more understanding and with diminished prejudice. In the first place the experimenters have taught us that all sorts of things injected under the skin and into the tissues will cause inflammation and that this is therefore not synonymous with infection. Dead germs do as well as the living, bits of metal and other foreign bodies, turpentine, "foreign" proteins, all bring about a similar change, which is not merely visibly the same to the naked eye, but even indistinguishable under the microscope. The small blood vessels in the neighbourhood of the infectio

open wide and admit a rush of warm blood from the deeper tissues—hence the visible redness and warmth. At the same time the blood vessels become more permeable and let fluid and blood protein, containing antibodies, through their walls, and this causes swelling. Also white cells from the blood are attracted to the inflamed part, and the bone marrow which makes these white cells steps up production.

All these changes follow the stimulus to inflammation, whether germ or other foreigner. How and why ? Professor Valy Menkin of Philadelphia has for some years been putting forward heterodox ideas on the subject, and now at last they are gaining some ground. He argues that the germ, the piece of metal, the turpentine, or other inflammation-starter, acts by damaging the skin it reaches, and this skin then gives off a number of chemical substances which make the blood vessels open, the swelling appear, the white cells migrate. Some of these substances he can extract from normal skin, and when injected again they produce some of the symptoms of inflammation. Leucotaxin attracts the white cells, leucopoetin stimulates the phagocytes, and so on. These substances still need a great deal of study by chemists. But the underlying idea is fruitful and probably sound. Inflammation is a complex natural bodily *reaction, carried out through the agency of hormones*. On its efficiency depends part of your natural resistance to infection, and the more that is learnt about this subject, the greater the hope of ultimately preventing all illness.

Dangerous Work

For some time now, research has been going on into a disease of newborn lambs called swayback (see an earlier report in *Science News* 3, page 52). This degeneration of the lamb's nervous system, leading to various kinds of paralyses, is prevented by adding a little copper sulphate to the diet. Now comes a startling medical report that out of eight research workers in a group studying sway-back

two or three years ago, four have since gone down with a nervous disease, disseminated sclerosis. This is ordinarily not a very common disease, so that it is startling to find 50% of the research group affected. In it, patches of degeneration of nerve fibres occur scattered throughout the spinal cord and brain, the patches slowly increasing in number as the years pass; and the symptoms produced are chiefly those of a creeping paralysis. Hitherto disseminated sclerosis has been regarded as a non-infectious disease of unknown cause and rather ineffective treatment. Mostly it went its own capricious course in spite of the doctors, and medical scientists were blank as to how to begin to investigate it, to improve this unsatisfactory situation. It seemed likely that the lead to a solution of the problems would come, as so often, from some quite other and unrelated branch of science.

Perhaps that is what has happened now. Perhaps a relation between swayback and disseminated sclerosis will be revealed, and this chance observation on the unfortunate scientists is no more than a straw in a possible wind.

Incidentally there is another aspect to the matter. Up to now there has been a great divorce between medical research and investigation of animal health. Yet fundamentally both sciences are aimed at the solution of similar problems, and it is to be hoped that the linking together of swayback and disseminated sclerosis is only the beginning of a closer collaboration between veterinary scientists and the doctors.

Jaundice

People turn yellow in sickness from various causes, and jaundice is therefore not a disease but a symptom. Sometimes it is a sign of sudden blood destruction, as when malarial parasites wreck the red cells on a large scale, and the sudden rush of decomposing red pigment stains the skin and eyeballs. More often it is the result of a blockage of the bile duct, or of damage to the liver itself.

One form of liver damage, to which considerable attention has been paid recently, is an infectious sort (therefore known as infectious jaundice or hepatitis) which occurred in epidemics in the armies in North Africa and the Middle East. It is apparently a virus infection (like the common cold), spread from person to person by direct contact and perhaps also by poorly washed cups and spoons or by flies, walking over food after buzzing round latrines.

In studying this particular disease, some of the most valuable information has come from doctors in country districts, where people live few and far between, and do not travel about very much. When the spread of Infective Jaundice through a population of this kind is followed, it becomes possible to time the contacts of the well and sick exactly, to say how long after infection a person lives before the yellowness appears (the incubation period is found to be one month), and during which stages of the infection such a person is himself infective. In fact in general, country practitioners are very well placed for studying the natural history of illnesses.

But when it comes to answering the question what the virus is doing in the body during the silent month before jaundice appears, or what is the best treatment, we must turn to the hospital and laboratory scientists. Treatment at present is confined to helping the liver in its convalescent period with plenty of protein (meat) food, and in particular with an aminoacid component of protein which contains sulphur, and is called methionine. Experiments on rats with livers damaged by arsenic or chloroform poisoning, or by very poor quality diets, such as the normal food of the Bantu native African, have shown that methionine in the food protects the liver to some extent. Fewer rats succumb to the poor food or the poisoning, more recover if already poisoned. It is not yet proved that this result applies also to humans. But doctors have no right to wait. They must start any possible treatment as soon as it is thought of, and leave the scientists trailing along behind

assessing and modifying in the light of further experience. At present, it is only fair to report the methionine treatment as not proven.

Rain

ERIC KRAUS

IN 1945 and 1946 an unremitting drought struck the North-Western districts of New South Wales. The pastures dried to dust, and the large flocks perished as weeks and months passed by without life-giving rain. Yet on many an afternoon dark heavy clouds built up into the sky, only to vanish again mockingly in the evening Where did these clouds come from? Why did they not rain? Could human ingenuity devise a method which might force them to yield their water? Recent studies allow us to give a fairly plausible answer to such questions.

Prologue

The molecules of any substance carry on an eternal dance. In a crystal they oscillate about their stations in the crystal grid; in a gas they rush hither and thither through space, colliding with each other all the time. The intensity of the molecular dance depends on the temperature. As a matter of fact, temperature may be defined as a quantity which is proportional to the mean kinetic energy of the molecules. The kinetic energy of any moving object—be it a molecule, a motor car or a planet—is given by half its mass multiplied by the square of its speed.

In a mixture of gases, the mean kinetic energy of the individual component molecules will be equal. The reason for this is easy to understand. When a big, heavy molecule hits a lighter one it will send the little fellow flying, just like a bulky footballer who collides with a frailer opponent. A little molecule hitting a big one, on the other hand, will make as little impression as a pebble thrown against a rock. This causes the heavy molecules to move in the mean less fast than the lighter ones.

When the earth was young, its atmosphere probably contained much hydrogen. Unlike the sun, and the larger of her sister planets, our small globe had not enough gravitational pull to retain the light and therefore fast-moving hydrogen molecules. Within a few thousand years most of them must have dispersed, shooting out into space like very fast rockets. The remainder combined with oxygen to form water vapour. As the atmosphere cooled further, the water vapour began to condense, perhaps at first only on the night-shaded side of the earth. Gradually the patches of condensed water spread. When they became permanent the first ocean was born.

Molecular Forces

When we lift a stone, we have to work against the force of gravity. The physicist says that this work is used to increase the potential energy of the lifted object. When the stone drops again, the potential energy which we have put into it is changed into the kinetic energy of the fall. Finally on striking the ground, the latter is converted into the energy of molecular oscillations, in other words, into heat, which is conducted away by the soil and the air.

Molecules too, as stars and planets, attract each other at relatively large distances. Yet when they are brought very near together a repellent force becomes predominant, which tends to drive them apart again. The potential energy associated with these forces is shown in Figure 3. We can compare this figure to the section across the surface of a valley. On the right side is a kind of plateau, where the potential energy alters little with distance. This means that the molecules exert no forces upon each other when they are fairly far apart. If we lessen the distance, the attractive forces come into play. The potential energy of molecules which move towards each other, now decreases like that of a stone which rolls down into a valley. At D in the valley bottom, a minimum of the potential energy is reached. In order to come still nearer together, the

molecules would have to be pushed up the steep slope of the repellent forces.

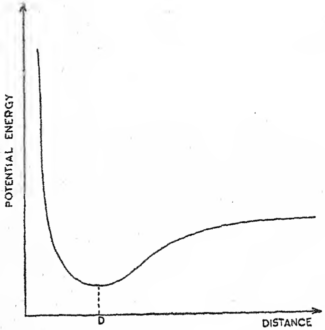


Figure 3

The attractive and the repellent forces balance each other at D. This corresponds to the distance between the molecules in their solid or liquid 'phase'. The actual length depends of course on the substance. The plateau on the right where the forces vanish again characterises the molecular distance of the gaseous or vapour phase.

Down in the valley at D, the molecules of solids and liquids rock left and right in their thermal dance. Every now and then, one gets an impulse which carries it right out of the potential valley on to the high plateau of the vapour state. It is then said to evaporate. Obviously those jerky molecules which overcome the bonds of attraction, and roll out over the brow of the potential slope, will be just those which oscillated most vigorously and had therefore much kinetic energy even in the liquid phase. The

mean of the molecular kinetic energy is continuously lowered by this escape of the fastest molecules, that is to say, a liquid is cooled by evaporation. The opposite happens when a fast vapour molecule hits the surface of a liquid. The impact will rock all the surrounding liquid molecules, and the increased kinetic energy of their thermal dance will make itself felt as increased heat—the so-called heat of condensation.

Water Vapour in the Atmosphere

There are always some vapour molecules over every liquid surface. Occasionally they will fall in and condense, whilst others take their place by evaporation. If the number of those reaching the liquid from the vapour is equal to those leaving the liquid we say that the vapour is saturated, or in equilibrium with its liquid.

The heating of water increases the violence of the thermal dance, and thus enables more molecules to escape from the potential valley of the liquid state. A vapour which is to be in equilibrium with warm water must therefore contain more molecules than one which is saturated relative to a colder surface. The saturation pressure increases accordingly with the temperature.

Cold air can contain but few vapour molecules. When it moves over a warm ocean, the number of molecules which it receives from below becomes much larger than the number of those which fall back. The moisture content of the air must thus increase. Enormous quantities of water vapour are supplied in this way to the icy winter winds of Canada and Siberia, when they flow out over the Gulf Stream or the warm currents of the North Pacific. Much vapour also reaches the atmosphere in the fresh trade winds in their passage over lukewarm tropical seas. In addition to these, but on a minor scale, every relatively warm and moist surface may serve as a source of atmospheric vapour.

Conversely, relatively warm air cooled from below loses

some of its vapour to the surface by condensation. Dew is an example of this: after sunset, the land cools quickly, and the warm night air deposits moisture on it. But the number of water molecules which evaporate from the surface of our planet is very much larger than the number of those which condense upon it. The difference is made up by a host of enterprising molecules which are of particular interest to us, and which we shall follow upon their adventurous journey.

The Formation of Cloud Drops

Much vapour is carried upwards by vertical air currents. These currents arise from the local heating of air, or by its flow across a mountain range, or by the convergence of horizontal air streams. Unfortunately we know as yet very little about the details of vertical currents, such as their extent or their speed. When air rises it expands. The molecules spread over a larger space and their kinetic energy decreases. In other words, rising air cools. Sooner or later it gets cold enough for its water vapour to become slightly super-saturated. If at this stage there was a water surface with the same temperature available, the moist air would lose more molecules towards it than it could gain. The excess moisture content would then decrease by condensation. As there are no permanent water surfaces in the free atmosphere, the vapour molecules tend to build them from scratch. They find that by no means easy.

The attractive force between two single molecules is much smaller than the force with which a whole group holds one of their number. This can be seen immediately in Figure 4.

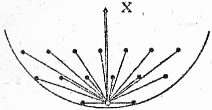


Figure 4a

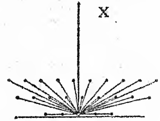


Figure 4b

The attraction between the individual molecules is represented there schematically by the thin lines, and the resultant force by the arrow X. This resultant force is always vertical to the surface. Its effect is similar to that of the elastic stress in a tennis ball. It compels any group of molecules in the liquid phase to assume a spherical shape. This roundness is characteristic for all small drops. A comparison of Figures 4a and 4b now shows immediately that a molecule in the plane or slightly curved surface of a large group is held by more bonds, and hence by a larger resulting force than one in the strongly curved surface of a small droplet. In the latter case the valley of potential energy must be shallow and the molecule has a better chance of escaping on to the plateau of the vapour phase. The small droplet therefore tends readily to disintegrate by evaporation, whilst the large one has a more stable character.

In particular, two molecules will stick together on an average for only about the hundred-millionth part of a second. If a cluster of three is to form, a third vapour molecule has to meet the pair within this interval. The trio can then expect to retain their association some hundred times as long as the first pair. When it is joined by a fourth one, before it breaks up, the quartet will live even longer .,. . and so on.

The average natural cloud droplet contains about 500 billion molecules. This is a very large figure. There are about two milliard men on earth, each of whom has probably less than five thousand hairs on his head. The number of all the hairs on all human heads is smaller than the number of molecules in the average cloud droplet. Such a large group can only gather from modest beginnings if there are a great number of molecular collisions within a sufficiently short interval. In order to create these conditions we need a highly super-saturated vapour, *i.e.*, a vapour which contains many more molecules than are necessary to maintain equilibrium with the droplet once it has formed.

Perhaps this can be made clearer by an extension of the

simile used for the interpretation of Figure 3. In the first instance we have now no potential energy valley corresponding to the liquid phase, but only the high level plateau of the vapour state. Let us imagine that the plateau is covered by a stretched elastic cloth which hides innumerable small hollows beneath. Picture the molecules as smooth like marbles, rolling at random upon the cloth. Singly each marble is so light that it rolls easily over the covered cavities. Yet if a sufficient number happens to meet simultaneously above one of the hollows, their combined weight may be sufficient to dip the cloth. When that happens, the molecules become trapped together in the depression, and they cannot as easily roll apart.

The chances of such an event taking place increase with the number of marbles on the cloth, and the time interval which they spend together on collision before bouncing apart. In a vapour these factors can be related to the pressure and the temperature. From these the chance occurrence of molecular gatherings is calculable. It appears that on an average only one drop will form in a cubic centimetre every thousand years, when the vapour pressure is three times the saturation pressure. At fourfold saturation pressure one drop could appear every second. Finally, when the vapour pressure is five times the saturation pressure a thousand million drops might form. This is borne out qualitatively by laboratory experiments with so-called cloud chambers.

Atmospheric vapour pressures are at the very most only a fraction—perhaps a few per cent—above saturation value, so our simple picture of drop formation cannot be correct. We must imagine then that the cloth is already depressed into the hollows by small weights, which have been placed there beforehand. The marbles will then quite easily gather in these existing depressions. In the real case our weights are actually small fragments of substances which have the property of attracting water molecules. Most substances have this property to a greater or lesser degree. It can be

observed in glass for example, when moisture droplets form on the cold window of a warm room. Ordinary cooking salt attracts water molecules so strongly from the atmosphere that its grains begin to clog the salt cellar on any moist afternoon.

Although the atmospheric condensation 'nuclei' must each contain millions of molecules, they are yet too small to be seen in the microscope. The majority of them are probably made up of (*a*) salt particles which are the residue of evaporating sea spray, (*b*) small blobs of nitric acid which is formed by lightning discharges, or perhaps in the wake of cosmic rays, and (*c*) of particles which come from the smoke of natural fires or from man-made combustion. Dust which is abundant in the air exerts no particularly strong attraction upon water molecules. The number of condensation nuclei is always sufficient for the formation of cloud droplets whenever the vapour pressure rises a fraction—a few per cent at most—above saturation value.

Why Clouds do not Always Rain

There is a great difference between the cloud droplets which first form around the atmospheric condensation nuclei and the drops which make up rain. The cloud droplets are so small, and they sink so slowly, that they evaporate after a fall of only a few inches below the saturation region. That is the reason why many clouds have such an even, well-defined base. Rain drops on the other hand are some million times as heavy. They fall fast, evaporate slowly, and they can reach the ground even through a relatively dry intervening layer of air. There is never enough water vapour in any cloud for all cloud droplets to grow to rain drop size. Only a few can do so. Obviously there must be an agency which allows some droplets to grow whilst others remain small. What is the mechanism of this selective process?

One possible factor is the unequal size of the droplets.

Above we have seen that the small ones evaporate more easily. Their disappearance will increase the host of vapour molecules which can be gobbled up by the bigger drops. As in some parts of the animal kingdom, we find a tendency for the biggest and strongest to grow still further at the expense of their smaller brothers.

But this curvature effect ceases to be effective for droplets above a certain size. The surface force and hence the rate of evaporation is practically the same as it is in a flat water surface for all droplets with a diameter larger than about the ten thousandth part of an inch. The average cloud droplet's diameter is roughly five times as large. This fact suggests that many cloud populations are actually the final product of the selective evolution, which may have started from unequal sizes in the beginning.

In some clouds the droplets do actually grow beyond that stage, yet the further growth is exceedingly slow. It requires a prolonged sojourn of the droplets in a slightly super-saturated surrounding. Conditions of that kind may prevail in slowly rising air currents, and in warm clouds which are cooled by radiational loss of heat. Even then, these clouds seldom produce more than a fine drizzle, whose small drops may reach the earth provided the journey is not too dry.

The big drops which fall from rapidly changing storm clouds with a high base cannot have grown this way. Their occurrence is now often explained by a theory which postulates that they have been born as tiny ice crystals in the upper part of the raining cloud.

Ice Crystals and some of their Properties

The qualities of crystals can be largely explained by the structure of their molecules. A planet's force of gravity depends only upon the distance from its centre. On the other hand the attraction which molecules exert upon others of their kind varies not only with the distance but changes also with the direction. Some directions are

greatly preferred. If conditions were similar on our earth, an apple might be a hundred times as heavy in China, say, as it would be in England. In a crystal, the molecules arrange themselves now in such a way that each one meets its neighbour in the direction of its maximum attraction.

The water molecules in particular consist of one oxygen atom and two hydrogen atoms. If we think of the oxygen atom as being in the centre of a three-sided pyramid or tetrahedron, the two small hydrogen atoms will sit on two of the corners, each of which carries a small positive electric charge. The two remaining corners have an equal negative charge. They serve as points of attachment for the positive corners of the neighbouring molecules. The resulting arrangement is shown schematically in plate 19 which represents the oxygen atoms as black balls, and the hydrogen atoms as white. It can be seen that the tetrahedral character of the water molecule leads to a hexagonal arrangement—the crystallisation form of ice.

In ice the molecules are so orientated as to be held by the strongest possible bonds. They cannot escape easily as those from liquid water. This small rate of molecular escape from ice can be made good by recaptures from a vapour which itself contains relatively few molecules. The crystal therefore persists in equilibrium with a vapour of lower pressure than does an open water surface. The difference of saturation pressure between crystals and drops is much larger than that between drops of unequal size.

The potential energy of ice molecules, with their strong mutual ties, is necessarily lower than that of the molecules in liquid water. When a water molecule freezes to a crystal it falls, symbolically speaking, into a very low pit of the potential energy. In doing so it gains kinetic energy which appears as heat passed on to the surroundings, just as in the case of the stone which hits the ground after a fall. This heat is called the heat of crystallisation.

The opposite happens on melting. With rising temperatures the thermal oscillations of the molecules become

more vigorous. This increases their chance of jerking out of that potential energy pit, which characterises the ice phase. When that occurs to a sufficiently large number, the regular crystalline arrangement is disrupted and the crystal melts. The heat which is necessary to bring this process about—the so-called heat of fusion—must be equal to the heat which was given up during the freezing process.

The collapse of the very open structure of the ice crystals causes a reduction of volume. In ice, the molecular arrangement needs much space; it is therefore light and floats upon the more densely packed water.

The Importance of Crystallisation Nuclei

The building up of a crystal, solely by the chance collision of vapour molecules, is even less probable than the formation of drops in that way. Although the attractive forces have always the tendency to bind the colliding molecules so as to form a regular lattice, they are opposed by the kinetic energy of the thermal motion. Only below perhaps —70°C. is the thermal energy weak enough to make the formation of pure ice crystals directly from a vapour at all probable. At higher temperatures drops rather than crystals will form in the first instance, when the super-saturation is sufficiently high.

Conditions are different in the presence of suitable nuclei. At temperatures below freezing point, the vapour molecules will tend to attach themselves to any existing surface or edge which recalls the structure of ice. By their combined forces any later arriving molecule will be orientated in such a way as to take up its rightful place in the crystal lattice.

It seems however that most of the crystals which occur in the atmosphere are not built up from vapour molecules at all. They are formed by the freezing of droplets. This event does not occur at the ordinary freezing temperature of 0°C. Perhaps the reason becomes clear if we consider that the water molecules have to be moved slightly apart

before they can click into their place in the crystal lattice. We may thus imagine the molecules of ice and water as lying in adjoining potential valleys. Because of a potential ridge between the two, it is impossible for the molecule of the liquid phase to fall—plonk—into the deeper furrow of the ice phase. It has first to pass over this energy hump. Only at very cold temperatures is this obstacle reduced to a kind of shoulder in a slope which leads fairly directly from the potential level of the water phase down into the pit of the ice phase. Because of this potential ridge pure water may be cooled to very low temperatures indeed. Liquid 'super-cooled' water drops have been observed down to —72°C.

The stirring of a super-cooled liquid may bring some of the molecules into the right configuration. A tiny crystal germ formed in this way will immediately grow very fast, and it will continue doing so until the whole mass is solid. The liberated heat of crystallisation may actually heat the water during the process. Alternatively, the freezing process may be precipitated by the introduction of suitable nuclei. Soil, stones and rock will always offer some surfaces which favour crystallisation. That is the reason why ponds and rivers freeze first along their banks and why these bodies of water can never be cooled much below the ordinary freezing point.

The air, too, contains many crystallisation nuclei which float about as very fine dust particles. Some of these will become embedded in cloud drops. As yet we can only conjecture their nature. They are much too small to be seen. However we do not know that they are not very efficient as a centre for crystallisation, for they only begin to act at temperatures of about —13 to —15° centigrade. Clouds which are warmer than that usually consist of droplets alone.

The crystallisation nuclei are apparently much less frequent than the ordinary condensation nuclei. Yet few and inconspicuous as they are they seem to have an

inordinately large effect on our lives, and upon the whole aspect of this planet.

Rainbearing Clouds

Let us now consider a cloud at freezing temperature which contains both crystals and droplets. Both a crystal and a drop of the same surface size will be reached by the same number of vapour molecules. But the rate of escape from the ice is smaller than that from the water-surface. Therefore the crystals grow much faster than the droplets. Within a short time the former will tie up so many vapour molecules that life becomes too dry for the latter. The droplets cannot take it. They evaporate and their former molecules attach themselves to the crystals. The process will continue as long as there are droplets about. Meanwhile the crystals are growing larger and larger. Eventually they form heavy flakes which fall towards the earth. When they come down to freezing melting level, the flakes thaw and each forms one or several big rain drops. During their further fall the raindrops may swallow those of the little cloud droplets which happen to be right in their path. That fortifies them sufficiently to survive even long dry passages down to the ground.

The effect is shown schematically in Figure 5. The small low cloud on the left does not even reach up to freezing level. It contains a population of modest droplets alone, and it will not rain as a rule. Equally little effect may be expected from the high cloud above with its exclusive ice crystal society. Even when a cloud rises above freezing level, as that in the middle, it will preserve its character as a homogeneous group of droplets. Only when the droplets are carried up to such lofty heights that some of them do attain crystal status, does the process of rain formation start. It is the beginning of the lost molecule's return journey back to the sea.

Not all rain forms in this way. Particularly in the tropics, precipitation has been quite often observed from

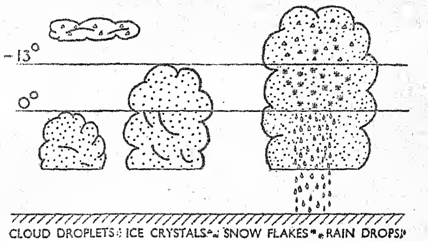


Figure 5

clouds, which did not reach up to freezing level. It appears that these tropical rain clouds are at least ten thousand feet deep. Whilst falling through such a massive cloud, the drops have much time to grow by condensation and by occasional collisions with each other. Yet even on the equator, all really violent downpours seem to come from clouds which reach well up into the crystal region. We may conclude, that although not necessary in every case, the existence of both crystals and droplets within one cloud will always greatly facilitate rainfall.

Man as Rainmaker

The argument so far represents the current ideas on the physics of rain. The development of these ideas during the last fifteen years suggested some possible alterations in the traditional rain-making methods of the witch doctor and the medicine man. Might it not be possible to sow tiny crystal germs into those clouds which rise above freezing level, but which do not quite reach the natural level of crystallisation? Such germs should grow like seeds in fertile soil. When they have grown big enough, they might bring the water down to the earth.

It has now been discovered that very large numbers of small crystal germs are formed when molecules collide in a very cold and highly super-saturated vapour. High degrees of super-saturation can be achieved simply by the rapid cooling of moist air. One way of doing that is to bring the air suddenly into contact with some very cold substance, such as solid carbon dioxide—or dry ice, as it is often called. The temperature of solid carbon dioxide is —80° centigrade. It is so cold that it will hurt your skin seriously if you keep it in your hand. When a lump of carbon dioxide is put on a table in a room, it seems to give off something resembling the bluish smoke of a cigarette. This smoke consists of tiny water ice crystals which form in the air as it eddies past the lump. If we drop a small pellet of the substance through the atmosphere, billions of tiny ice crystal germs form in its trail. If all these small crystals would spread throughout a cloud of super-cooled droplets, each one of them might grow to become a big snowflake, and hence a raindrop. If this were the case, one grain of solid carbon dioxide would be sufficient to release an inch of rain over several square miles. In reality, the tiny germs do not migrate sufficiently. They remain in a relatively limited region, where the competition between them for the available water vapour is so large that only a fraction has a chance to grow. How many will actually do so depends on the type of cloud into which the carbon dioxide has been sown. In particular it depends on the amount of water, on the temperature, turbulence and other physical properties. At present we know very little about these factors inside clouds. Empirical tests have shown however that a hundred to three hundred pounds of granulated dry ice are ample to stimulate an appreciable fall of rain from suitably selected clouds.

Instead of forming crystal germs spontaneously by rapid cooling we could sow particles of other substances into super-cooled clouds. Provided the structure of these particles is suitable, they will serve as nuclei for crystallisation

at a level which is lower than that above which the natural nuclei begin to act. Clouds which are not supercooled could be affected by being sprayed with a hygroscopic substance. These substances bind water molecules strongly, and this property causes big drops to form around them. Recent reports indicated indeed, that rain has been precipitated in Russia, by the dusting of clouds with Calcium Chloride, which is a very hygroscopic chemical.

Once crystals are made to grow by any sort of method the heat of crystallisation will be released. The corresponding gain of heat in the whole cloud mass is much greater than the amount of cooling in that part, through which the carbon dioxide had been dropped. The infected cloud thus becomes slightly warmer than the surrounding air. Warm air rises, and that often causes the remarkably fast growth of thunderclouds into the sky. Something similar happened on some of the tests, when artificial crystal germs were planted in clouds over New South Wales. The clouds shot up in a most spectacular way, and when they towered high above all the other clouds, rain came

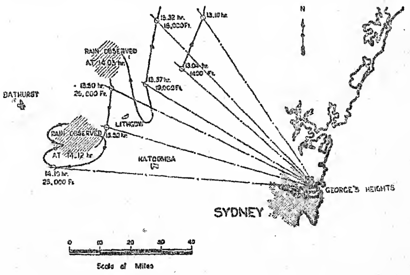


Figure 6—Radar plot of the aircraft track and the two areas where rain echoes were observed to form

out of their base. Plates 20 to 25 illustrate one of these events (see also the map, Figure 6).

To those who carried out the test, this was a thrilling sight. Unfortunately we are not sure as yet how easily it can be repeated. When these first experiments were planned, it was obviously desirable to pick out the most favourable conditions. For all we know at present such conditions may rarely occur.

Before rain-making ceases to be a gamble, it is necessary to learn something of the physical properties of various cloud types, and to observe how often they occur in a given region. This is a fundamental investigation which will occupy scientists for many years. It involves great theoretic and instrumental difficulties, such as computing the relations between vertical air currents and the temperature, air pressure and moisture; or measuring the sizes and numbers of cloud droplets from fast-flying aircraft.

If successful, this investigation ought to teach us something more about the physics of clouds. That is a satisfactory and legitimate aim in itself. With luck, we may get the additional benefit of learning how to cause a slight increase of rain in certain areas. Perhaps we shall find a way of choosing the place on to which it falls. Any discovery of that kind would be of great importance to the people who live in the semi-arid parts of Australia, India and other similar regions. Without further fundamental investigations we cannot say what will or will not be feasible.

One thing is certain. At present we cannot make rain. We can only trigger it off from suitable clouds. This fact alone should preserve us from rain falling according to a departmental schedule as trains follow the railway time table. For the time being at least, we will be still caught out—with or without umbrella—and we need not fear the fading of an old experience which is varied, often stimulating and never quite predictable.

Roads are being made Waterproof

C. S. JONES

MANY types of synthetic resins—particularly the melamine groups—are coming to the fore both in the manufacture of plastics, and the processing of textile fabrics for crease-resistance and anti-shrinkage. They also have another use—to make roads "waterproof". They are, of course, largely used in those sections of the textile processing trades where proofing against moisture penetration in fabrics is desirable, but their application to other substances, such as soils, is a striking innovation. It comes from experiments which were undertaken in the U.S. during the war period. It was noticed that miles and miles of roads, on which heavy trucks would travel during the winter months, turned to seas of mud after torrential rain, and remained in that condition until the sun's rays turned them into dust-covered highways. Most of the roads were too far off the beaten track to allow them to be paved or treated with creosoted layers, yet something had to be done. It was Dr. Winterkorn, a soil expert, who emigrated from Heidelberg to U.S.A. in 1931, who accepted the challenge. He got on to the right track, strange to say, through an unrelated problem that arose in Florida. Citrus trees in certain districts were dying; apparently the particular soil in which they had been planted would not absorb water. Dr. Winterkorn deduced that the soil must contain some kind of a "waterproofing" agent. He followed up the clue, tested scores of materials, and found that a number of resinous powders would waterproof surface soil when mixed with it in a ratio as low as 1 to 200. He set to work on his thesis. In collaboration with a chemical manufacturing

firm he developed a resin from pine stumps. A mixture of this resin and Portland cement was evolved. Applied in disc form and rolled into the ground to a depth of a few inches, it was found that the surface was impervious to rain, or snow penetration. Thousands of miles of "dirt" roads have since been treated, and reports prove that they have remained dry through seasons of torrential rains and are likely to do so for some years hence.

But, it is pointed out by the inventor, it would be a mistake to assume that anyone can sprinkle any road with this "magic powder" and end the mud nuisance for all time. On the contrary, to effect satisfactory and permanent results soils must be analysed, and experts must apply the correct type of resin stabilizer. This is all the more necessary when it is borne in mind that acid and alkaline soils react differently. No known resin will waterproof sand, nor will it stand up under heavy traffic.

How Messages are Transmitted along Nerves

DR. W. A. H. RUSHTON

Introduction

As soon as animals evolved even to the stage of quite small collections of cells, it became necessary for them to arrange for the transport of chemicals between the central region and the outside. It also was advantageous to have some degree of communication between different parts, and from the first use was made of the transport system to distribute potent chemical messengers (hormones). These hormones are synthesised by certain cells, and may be liberated into the circulation as a result of specific stimuli and so carried to remote parts of the body. The particular feature of the hormone is that it will act upon certain cells and not upon others, so that a special kind of response may be elicited. This has proved a very successful biological device, and physiologists continue to find more and more ways in which our own bodies depend for healthy working upon the scores of hormones circulating in our blood.

But as a means of communication, the hormone system has two important limitations. It is slow, and it is poorly localised. In ourselves, where the chemicals are poured into the veins and carried round in the blood stream, it is obvious that the message cannot be sent faster than the blood travels. It takes about 20 seconds for the blood to complete the circuit of body and lungs, and so we cannot expect to obtain by hormone a response to any stimulus within 10 seconds. Again, since the blood is distributed to every part of the body, the hormone, after thorough mixing in the lungs, must broadcast its message indifferently

no matter what may be the site of stimulus. This slow reaction and poor localisation, however, is no drawback where the processes of growth, digestion and general chemical equilibrium are concerned, and it is in this domain that hormones are particularly effective.

But when we turn from considerations of vegetative existence to the relation with the environment, a quicker and preciser system becomes essential. A prime requirement is for the organism to react appropriately to danger or food, and, on the whole, survival rewards him who appreciates the situation most accurately and does the right thing quickest, whether flight or pursuit.

The nervous system is the biological response to these needs. Nerve fibres are like telegraph wires in that they transmit messages fast and far with no transport of material and little expenditure of energy. Information from the outside is received by specialised cells, the sense organs, and these transmit nervous impulses which very quickly reach muscles or glands and stimulate them. It is rare to find a direct connection between a sense cell and a muscle —a private line, as it were. A private line system between *each* sense cell and every muscle that it might require to excite would be very unsatisfactory from two aspects. It would require an enormous number of nerve fibres, and worse still, there would be no co-ordination of the often quite conflicting "orders" sent out from the various sense organs. Thus from the very beginning of nerve evolution there has been a tendency to *centralise* the nerve connections so that a central exchange receives the messages from the sense organs and relays them (to muscles and glands) more or less modified in accordance with the totality of the information received.

It seems obvious that an animal will not be able to react very well to external conditions unless it has good information about those conditions, and this information is entirely supplied by the sense organs—cells specialised to respond primarily to mechanical or chemical changes in their

surroundings. The ear and the eye are wonderfully elaborate examples of such specialisation where mechanical resonance and photochemistry are enlisted to enable the cells to appreciate waves emanating from distant objects, and hence to give us some information about the remoter world.

There is perhaps one exception to the statement that all outside information comes to us through the sense organs, namely the case of telepathy. We have a considerable body of rather scattered evidence that perception may be directly transmitted from one mind to another without any sensory intervention. But because it is hard to obtain the conditions for successful telepathic transmission, and because the implications of telepathy are considerable, we must, at present, be careful as to what we build upon this foundation.

It does not seem as though telepathy should affect very greatly the idea that our information about the outside world is entirely supplied through sense organs. These organs would indeed not necessarily be our own, but a very great body of our information in any case is at second hand—read and heard by our own eyes and ears but lived in our imagination through the senses of the narrator. What telepathy brings new is that among the assortment of impressions which pop into consciousness from our own unconscious mental processes, there are occasional impressions which come from someone else's mental processes, and may carry the authority of his sensory perception.

Even accepting telepathy, therefore, our concept of the outside world is derived from the impulse patterns in sensory nerves—indeed this is probably implicit in what we mean by "outside world".

The part played by nerves in the body is so reminiscent of a telegraph system that it is easy to overlook the fact that the message is transmitted by an entirely different application of electricity in the two cases. To illustrate this difference let us consider two familiar ways in which heat may be transmitted.

If a metal rod has one end warmed in a flame, heat will pass along the rod and the temperature will rise even at quite a distance from the flame, especially if the rod is lagged with a thermal insulator. Contrast this system with a lighted cigarette. Here too applied heat may result in the propagation of a temperature rise to a more or less distant region, but the mechanism of propagation is obviously very different. The metal rod is throughout quite passive. Heat is applied, and leaks away where it can. The metal conducts well, the air or other surroundings conduct badly, so that most of the heat passes down the metal, and thus will penetrate some distance with gradual loss of intensity. Any increase in the temperature of the source results in a proportional increase in temperature everywhere in the rod.

The cigarette, on the other hand, is in active combustion. It is not the heat of the match which is conserved and transmitted down in the advancing glow. The match is the trigger which releases the chemical potential of the tobacco, etc., in the cigarette, and the glow is the manifestation of the energy liberated by combustion at the moment. The intensity of the glow will thus not depend upon the temperature of the match (provided that this is adequate to light the cigarette) nor will the brightness decline with the distance of propagation.

Now telegraphic propagation is like the metal rod, and nerve propagation like the cigarette. For the telegraph wire transmits the electric wave owing to good conductivity along the wire and good insulation in other directions, and the size of the wave is proportional to the intensity of the applied electric charge, and gets weaker with distance. But in nerves the activity spreads from point to point by the release of local electric potential. So the impulse does not diminish with distance, nor does its size or nature depend upon the strength of stimulus which excites it to activity (the All-or-None relation).

This is an astonishing limitation. It seems so obvious

that a strong external stimulus such as a bright light or a severe pinch must set up a larger impulse in the nerve fibres than a slight stimulus. But though, of course, the nerve message is not the same for strong and weak stimuli, the difference does not lie in the size of impulse conducted, for this depends, not upon the external stimulus, but upon the local conditions of the nerve. Since the only knowledge that we have of the world outside ourselves comes through our sense organs and their nerves, it follows that the shifting pattern of sensory impulses comprises the totality of what we know of the Universe, of Mankind and of everything outside us. All else is the fabrication of our mind. Our familiar picture of the outside world must therefore be largely superfluous, but that it tallies well enough with external reality in certain particulars is shown by the steady advance of verifiable knowledge, *e.g.*, the prediction of eclipses.

We cannot pursue the fascinating question why our concept of the outside world appears so very different from any conceivable integration of the patterns of nerve impulses. It must lie in the properties of the mind which is not solely, nor even chiefly, concerned with exact appreciation of facts. But in the study of the nerve impulse we view at least the bricks from which the mind must build its edifice of factual knowledge.

The Kind of Nerve Studied

While a nerve is in the living body it is rather inaccessible and thus most accurate measurements are only practicable after it has been dissected from the dead animal and set up in special apparatus. It might well be thought that nerves in this state were so moribund, that the information obtained from them was inapplicable to living conditions. Fortunately this is not so.

If an animal is killed quickly by almost any method (*e.g.*, decapitation), though the animal is dead, the nerves of the body are alive. They remain capable servants,

though lacking a master. Even after being dissected out they continue to respond to electric shocks in just the same way as they did in the living animal, and they may survive in this state for many hours or even days. So most of the observations made upon carefully dissected nerves apply pretty well to nerves undisturbed in the body.

Now it might be thought that the nerves of man would show particular properties not exhibited in animals whose nervous systems are less specialised. It appears, however, that specialisation has been concentrated upon the nerve centres, which become more and more elaborated as we ascend the evolutionary scale. The simple transmission line—the nerve *fibre*—remains essentially the same from its earliest appearance in the sea anemone, through worms and crabs and squids, to frogs, dogs and man. The study of human nerve conduction therefore need not wait upon the rare opportunity to dissect out a living human nerve, for almost any creature will serve. Frogs have been most commonly used, but we will first consider the giant nerve fibre from the squid, which on account of size may be studied more directly.

The Resting State

The giant nerve fibre of the squid is nearly a millimetre in diameter, which is some hundred times as thick as the nerves in our body. This nerve is a cylindrical tube whose wall is exceedingly thin and fragile, and whose contents are so fluid that they flow out of the cut end unless it is tied.

To understand the cigarette analogy we must learn what is the nature of the stored potential energy, and in what manner it is released so as to propagate an impulse.

Figure 7

The electrical condition of the fibre's interior has been found by inserting a fine electrical probe. Fig. 7 shows the nerve bathed in sea water to keep it from drying up. Down the centre is a fine wire sealed in a glass capillary tube to insulate it except for the tip, T. The greatest care is needed in inserting the tube, since the nerve is fatally damaged if its wall is touched. But with sufficient skill, the tube may be introduced and left in position down the middle of the fibre with so little disorganisation that the nerve survives and conducts impulses quite normally.

Now if the wire is connected as shown through a voltmeter V to the sea water bathing the nerve, the instrument will record the potential across the nerve membrane. The voltmeter must not draw current, and actually a valve-amplifier was used in conjunction with a cathode ray tube, so that sudden changes in membrane potential due to the passage of the nerve impulse could be instantly recorded.

Now in the resting state there is found to be a potential difference of about 1/20 volt across the nerve membrane, the inside being negative. This is analogous to the chemical potential of the interior of the cigarette and may clearly be the source of the energy required for the propagation of the impulse.

Those who associate electricity chiefly with metals may be surprised to learn that the nerve is able to make its battery without metal pieces and with no other ingredients than are to be found in sea water. Such batteries are of no use in electrical industry, because they give hardly any current, but they arise in general whenever two different salt solutions are brought in contact.

In the case of nerve, the battery of 1/20 volt is directly related to the chemical composition of the fluid inside the nerve. This fluid can be squeezed out and analysed, and it is found to contain potassium in a concentration 30 times that of sea water. Why does not the potassium leak out into the sea water? The obvious suggestion is that the nerve membrane is "potassium-tight", but this is not

the case. If some potassium is added to the sea water outside the nerve, it will enter the nerve, actually going from the dilute to the concentrated solution; as may be proved by direct analysis. But if potassium *can* pass through the membrane why does it remain concentrated inside? The reason is electrical. Potassium in solution has a positive charge which must always be neutralised by association with another chemical negatively charged, *e.g.* with chloride particles in sea water. Now inside the fibre the negative particles are part of the nerve protoplasm, so when the potassium seeks to escape from the interior it is held by its attraction to the protoplasm. An equilibrium is thus reached where the tendency of the crowded potassium particles to leak away is exactly compensated by the electrical potential difference (negative inside) impelling these positive particles to return. From the known potassium concentrations in sea and in nerve it is possible to calculate the membrane potential difference necessary to restrain them. This agrees with the value found by the experiment of Fig. 7.

We thus conclude that the resting potential difference across the membrane is due to the fact that the inside of the nerve contains concentrated potassium which could escape, were it not for the electric attraction to the fixed protoplasm.

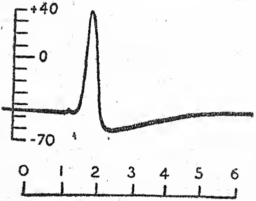


Figure 8

The Active State

Now, turning again to Fig. 7 let us consider what happens when the nerve is excited by applying a shock through the electrodes S, situated some distance away from T. If the shock is weak, nothing will be recorded, and if in succession stronger and stronger shocks are applied, practically nothing will be seen in the voltmeter record until suddenly the response shown in Fig. 8 appears. Shocks stronger than this "threshold" value continue to give just the same record. The response is therefore like the cigarette glow, which is not elicited at all unless the lighter is hot enough, and which is of the same brightness no matter how much hotter than threshold the lighter may be (All-or-None). This record, then, is related to the energy release of the nerve in activity, and repays closer inspection. The time scale is in thousandths of a second (msec.) so the changes are exceedingly rapid. The vertical scale gives the potential of the inside relative to the sea water as zero, and shows that the resting condition (1/20 volt negative) swings over momentarily to about 1/20 volt positive. The wave is preceded by a tiny upward notch. This represents the physical spread of the stimulating shock. It is the only thing recorded when the stimulus is below threshold strength, and it serves to show the exact instant when the shock was applied. The short interval between the application of the shock and the beginning of the nerve response is the time taken for the nerve impulse to be conducted from S to T. Records obtained when S is moved further and further from T show corresponding increases in the interval between the notch and the wave in the records, and from such comparison the impulse is found to travel at a constant speed of about 20 metres per sec. (=45 m.p.h.).

In suggesting that the electric wave is analogous the to glowing reaction of the cigarette we have implied that the wave *is* the energy change responsible for propagation. Suppose we had suggested that the wave was analogous to the smoke given off from the cigarette, this would have

of sodium chloride, but the inside of the nerve contains little sodium, so that there is a disparity of sodium across the nerve membrane like that of potassium, but in the opposite direction. Now the sodium cannot be restrained by the electrical forces, since these actually urge positive particles inwards (as we have seen). So we must conclude that the nerve is like a ship which will not allow the sodium of the sea to accumulate within, either because it is "sodium-tight" or because the pumps are kept working (as recent work with radio-active isotopes suggests).

Now suppose that a shock breaches a hole in the ship's side so that sodium pours in—for, though no visible hole is made, the electrical resistance of the nerve membrane suddenly falls nearly to zero. The inrush of positive particles may well cause the positive swing of the potential seen in Fig. 8, and sodium will replace some potassium in the protoplasm and thus account for the observed escape of potassium to the exterior. But how does the shock "breach a hole" in the nerve membrane? We are familiar with the material property of "giving way" before too great a strain. The safety valve will yield, or the boiler will burst, or the string will snap, or the electric insulation will break down, if the applied tension is excessive. Not so is the membrane response.

There is a more subtle set of devices which we know well—knots, buckles, ratchets, catches and friction jams of all kinds. The trick about these things is that if you would loosen them you must first oppose the motion which is your ultimate object. Swell your belly and you may burst your belt, but it will never unbuckle that way. If you would ease yourself, first tighten a little.

Figure 10

The nerve mechanism lies in this class, for an electric current will only stimulate when it passes through the membrane in the direction opposite to that of the active discharge. The current has first to depolarise the nerve, i.e., to lessen the resting electric strain. This lifts a restraining catch, and now the system rapidly discharges until the fall of the catch again restrains it. A row of bricks standing on end can propagate a wave of collapse (Fig. 10) in this way. Each brick is a "catch mechanism" in that it needs the centre of gravity to be lifted a little before it can fall, and the fall of each releases the catch of the next.

The Living Nerve

We have considered the propagation of a single impulse along a stretch of nerve fibre, but to view this in its perspective as a bodily activity needs some extension both in time and space.

Normally impulses follow each other down a nerve fibre in more or less rapid sequence, which brings us to the question of the recovery process, maintenance and fatigue.

Again, the significance of an impulse train lies in what it does at the other end of the line, and this involves nerve-muscle action at one end and central nervous coordination at the other.

The present account of nerve conduction will therefore conclude by touching upon these questions in order to show the nerve impulse a little more clearly in its biological setting.

Recovery

As soon as the wave of activity is ended at any place in the nerve, this place is ready to conduct a second wave. The fastest nerve fibres of our bodies can conduct up to a thousand impulses per second, though they are rarely called upon to exceed half this frequency.

The fact that a nerve is ready to conduct again as soon as the last wave has passed, shows that the resting potential

energy is not all used up (as in the case of the cigarette) and this is confirmed by the return of the wave (Fig. 8) to the former resting potential level instead of to zero.

Either, like the escapement of a clock, the catch falls again before very much of the potential energy has run down, or else, like a water closet tank, there is connection with a much larger reservoir, so that the tank may be emptied by the local action but is then rapidly refilled from the reservoir. This last example constitutes quite a good analogy for what in fact is found. The discharge from the tank is independent of the strength of stimulus (All-or-None relation). Immediately after the discharge there is a short period during which a second discharge cannot be obtained, no matter how strong the stimulus (absolute refractory period). And following this there is an interval during which the stimulus required is greater

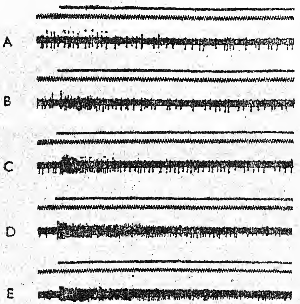


Figure 11—Records of nerve impulses from the eye when a light is switched on. The top line in each group shows the illuminated period, the thick black line with fringe is the nerve-impulse record. A to E. progressively brighter light.

and the discharge resulting is smaller than normal (relative refractory period).

This latter property may be of great importance in helping us to appreciate the world outside us. We have seen that the only way in which a nerve fibre can vary its message is by altering its rhythm. But the information which it seems to convey is about the *strength* of stimulus (*e.g.*, brightness of light, severity of a pinch, etc.) not its rhythmic quality. Since a strong shock is needed to excite a second impulse rapidly after a first, only an intense stimulus will be able to generate the highest frequencies of impulses. Inversely, it is likely that strong stimuli at the body surface are inferred when a fast train of impulses arrives at the brain.

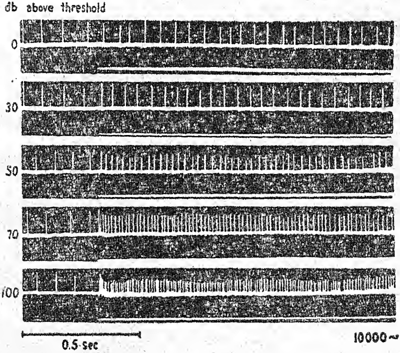


Figure 12—Records of nerve impulses from the ear in response to louder and louder sound. The lower white line in each record shows when the stimulating sound is made.

It would be misleading to suppose that the foregoing was the only or even the main causal chain between the intensity of stimulus and the nerve pattern received by the brain, but it shows one way in which the brain may appreciate stimulus strength, despite the unvarying size of nerve response. Actual records from a single nerve fibre of the eye and the ear are shown in Figs. 11 and 12. The stronger the light or sound, the more closely the impulses follow each other, but there is no change in their size.

Fatigue and Maintenance

We are familiar with one idea of nerve fatigue—the condition which is cured by sleep, or a holiday, or even a change of work. Whatever this phenomenon may be, it certainly is not a property of conduction in the nerve fibre. For nerves will continue to conduct impulses at the rate of 100 per second for hours on end without showing any sign of fatigue, and in cases of complete "nervous exhaustion" the nerve fibres still appear to be normal. No, nerve fatigue is an affection, not of the fibres but of the nerve centres (brain and spinal cord), which have some properties very different from those we have been considering. But though our nerve fibres are unfatiguable in ordinary circumstances, they need a more or less constant blood supply if they are to maintain their function.

If we stay for some time with one knee crossed over the other, the upper foot may "go to sleep" and become quite numb. Many people suppose that this is because the artery behind the knee has been compressed and so the foot is deprived of its blood supply. You may satisfy yourself that this is not the case, however, on the next occasion that your foot goes to sleep. For, while maintaining the "numbing position" of the legs it is easy to insert a finger behind the knee and feel a clear space there with no contact, far less compression, upon the region where the artery runs. More convincing still, the pulse may be distinctly felt in the foot.

There are two places on the foot where a pulse may normally be felt, though not so strongly as at the wrist. One is in the midline in front at about the level of the ankle bones, and the other is just behind the inner ankle bone. These pulses may be felt to beat quite normally when the foot is "asleep", proving with certainty that leg-crossing does not cut off the blood to the foot.

What is compressed, however, is a nerve which runs over the bone (neck of the fibula) on the outer aspect of the leg just below the knee. This comes nicely in contact with the knee-cap of the lower leg and so the nerve is pressed between the two bones. But, it may be asked, "If the nerve is pressed near the knee why is it *the foot* that becomes numb ?"

Perhaps you have given this nerve a knock (as I often have) when carrying a suitcase. You will then have noticed that in addition to the ordinary sense of being knocked, there is a special tingling chiefly in the foot.

Nearly everyone has experienced a similar thing on knocking the "funny bone"; though the inner aspect of the elbow is struck, the special tingling is felt in the region of the little finger.

Now if by anatomical dissection we trace the course of these nerves which lie near the surface at knee and elbow, it is found that the fibres end in the very places where the tingling is felt. So it appears that if we bump or paralyse a nerve trunk, we get tingling or numbness "referred" to the place where the fibres have their distant endings.

This result is a necessary consequence of the idea, stated earlier, that our only information of the outside is conveyed by nerves in unit impulses. For since the impulse which arrives at the central nervous system is the same whether it starts at the nerve ending or is generated by a bump on the "funny bone" half way up the nerve, the centre cannot distinguish between the two and simply says "I am getting impulses in the fibres which normally conduct from the little finger". In the same way when the leg nerve

stimulated electrically by the nerve action current. But where this has been most carefully studied it is found not to be the case.

In considering earlier the objections to stimulation by hormones, we noted that the chemical message travelled too slowly and was broadcast too freely, Both these objections would be overcome if the hormone were secreted not by one general gland discharging its products through the blood stream, but by a sprinkling of minute gland elements situated one at the termination of each nerve fibre. For the message would travel swiftly down the nerve, and the hormone would be intimately applied to the structure at its termination. In the case of every nerve which conducts away from the central nervous system it has been found that there is in fact such a hormone secreted. The hormone is not the same for all nerves, but in each particular case it is found that the next cell (muscle, gland or another nerve cell) is sensitive to the external application of this particular hormone. Thus there is strong reason to suppose that the nerve *ending* stimulates by the intimate application of a minute dose of hormone.

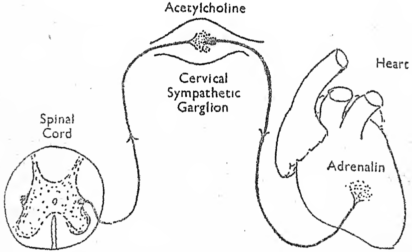


Figure 13

Fig. 13 shows schematically the sympathetic nerve relay which runs from the spinal cord to the heart and makes it beat faster. The first nerve runs out from the spinal cord to a nerve centre (ganglion) in the neck. Here it secretes acetylcholine, which hormone will excite the second nerve leading to the heart. The second nerve ending secretes a different hormone, adrenalin, which acts upon the heart and quickens the beat. The heart is quickened in the same way when adrenalin, synthesised chemically, is injected into a vein and in this manner carried to the heart, or when the adrenal gland (a typical hormone-producing gland) pours adrenalin into the general circulation. In the latter cases, however, the effects are not simply confined to the heart but are widespread, and appear after a greater delay owing to slow blood transport.

We have spoken of the special properties of the endings of outgoing nerves. What of the incoming nerves that ramify in the tangle of the central nervous system; do they operate by electricity or do they also secrete a single hormone or one of many?

As yet we do not know. There are many close analogies between central nervous conduction and the peripheral conduction where hormones are found to act. But we may not conclude that hormones must act centrally too, because there are many central features which have no peripheral counterpart. Moreover Nature has a trick of producing the same end result by totally different kinds of mechanisms, so we must exercise caution in the application of analogy.

The reader must therefore be left to speculate for himself how far his nervous coordination, his reinforcements and his inhibitions are due to the accumulation and antagonism, the drift and the destruction, of chemical agents in his brain.

H	C_2H_5	C_2H_5
O	O	O
H	H	C_2H_5
water	alcohol	ether

Here he is, in effect, giving to an atom of oxygen the power to combine with two groups—what was later called a *valency* of two.

In 1852 Edward Frankland took a further step forward and, as a result of his studies of the organic compounds of nitrogen, phosphorus, arsenic and antimony, came to the conclusion that an atom of these elements would combine with *three* or *five* atoms of hydrogen, chlorine, iodine or oxygen (O=8). A. S. Couper, in 1858, introduced the idea of the quadrivalency of carbon and the familiar valency bond of today. Couper unhappily fell ill and it was left to Kekulé to develop these ideas. In this year, Cannizzaro wrote his famous pamphlet which established true values for atomic weights, and these, with the idea of valency (combining power) and valency linkages, allowed structural chemistry to begin its course.

The relationships between the valencies, chemical properties and atomic weights of the elements is bound up with the Periodic Law of Mendeléeff. The central idea of this, that there were relationships between the atomic weights of chemically similar elements, came near to discovery in this country, for the tables of the elements put forward by John Newlands and by William Odling contained the essential idea of Mendeléeff, though they lacked the masterly exposition of the evidence and exploration of the consequences that distinguished the work of the Russian savant.

The greatest contribution of British men of science to the problem of the relationships between the valencies, properties and atomic weights of the elements was the brilliant series of researches, employing physical techniques, that led up to the theory of the structure of the atom. We may first remember the hypothesis of William

Prout (1815) that all atomic weights were exact multiples of that of hydrogen, which, although contrary to the facts then known, was found after the discovery of isotopes to have a substratum of truth. Then we turn to William Crookes's investigations of cathode-rays (1879), which seemed to him to contain a 'fourth state of matter'. J. J. Thomson in 1897 proved these rays to consist of streams of negatively charged particles very much lighter than the lightest atom. These particles, later called 'electrons', could be elicited from every kind of matter and formed the first evidence of a factor common to all the elements. At this time X-rays had been discovered by Röntgen and this had led to the researches of Becquerel and the Curies, which established the existence of radioactivity and its association with certain metals. The nature of this phenomenon was first made clear by Ernest Rutherford and Frederick Soddy, who showed that radioactivity was the disintegration of atoms and that the radioactive elements were being transmuted into other elements. Soddy's discovery of isotopes, elements of apparently identical properties but different atomic weights, explained the anomalies that had been noticed in the Periodic Table, and, since that date, F. W. Aston's invention of the mass spectrograph, a development of J. J. Thomson's positive ray-apparatus, has shown that almost all elements are mixtures of isotopes. The disintegration theory of radioactivity led Rutherford in 1911 to put forward the nuclear theory of the atom, giving evidence that it consisted of a positive nucleus, minute but possessing nearly all the mass of the atom, surrounded by a cloud of electrons. The nucleus of the hydrogen atom he called the *proton*. This theory gave a theoretical foundation for the periodic table. The number of the element in the table, starting from hydrogen as 1, was taken to be the nuclear charge, and this was proved by H. G. J. Moseley who, utilising Bragg's method of X-ray spectroscopy, was able to determine the atomic number of an element from the frequency

of the X-rays emitted by it when used as target in a cathode-ray tube. On these British researches Niels Bohr founded his brilliant theory of the structure of the various atoms, and the groups of electrons that characterise the elements of each group of the periodic table. This work also led to the understanding of chemical combination, for N. V. Sidgwick, gathering together a number of partial explanations, showed how the Bohr atom accounted for the three different types of valency—the electrovalency of salts, the covalency of organic compounds and the co-ordinate valency of the ammines and other such compounds, and thereby opened up many new lines of research.

This work has thus brought us to a useful, if not complete, knowledge of the relationship between the different types of atom, and of the manner in which they combine. The deduction of the *arrangement* of the atoms in the molecule, indicated by the structural formulæ of chemical compounds, has been perhaps the principal work of chemists during the past century. It is impossible to recount the various methods employed, for each compound presents a different problem: suffice it to say that reasoning based on observed properties and reactions has settled the formulæ of all the simpler compounds known to us, and in recent years this has been supplemented by several physical methods.

But in chemistry we do not deal with single atoms or molecules but with aggregates of them—solids, liquids, gases, solutions and mixtures—and so the study of the physical properties of the various chemical compounds has proved to be necessary to the understanding of their chemical reactions. No part of Physical Chemistry, as this study is termed, has been more important than the investigation of the properties of gases. The first president of the Chemical Society, Thomas Graham,* discovered the laws of diffusion of gases, which gave us a new means of determining their densities and the first physical means of separating two gases. A tremendous amount of funda-

* See Plate 32.

mental physical and mathematical work on the kinetic theory of gases was done by such men as Clerk Maxwell, Joule and Kelvin, though this belongs rather to physics than to chemistry; but a very important contribution, both theoretical and practical, was made by the many British chemists who studied the liquefaction of gases. Davy made a beginning, and Faraday, between 1823 and 1845, liquefied all the known gases that could be condensed by cooling to –110°C. at pressures up to 50 atmospheres. Certain gases resisted his efforts, and Thomas Andrews in 1869 put forward the theory of the *critical state*, and thereby showed the impossibility of liquefying gases above their critical temperatures. Efforts to liquefy such gases as oxygen, nitrogen and hydrogen continued to have small success until 1895-6, when Linde in Germany, and James Dewar and William Hampson in England, made use of the Joule-Thompson principle (1853) that a gas is considerably cooled when it is allowed to expand from a state of high compression. This, combined with regenerative cooling, led to the liquefaction of all known gases by 1898, in which year Dewar liquefied hydrogen. M. W. Travers, in 1900, made a small and simple laboratory plant for this purpose and so opened the way to the low-temperature researches which have been essential to so many of the discoveries of the last forty years.

The contribution of British men of science to the theory of the structure of solids has been fundamental. During the nineteenth century our countrymen took only a modest part in crystallography, but in 1912 came the epoch-making discoveries of W. H. and W. L. Bragg, who developed Laue's discovery, that X-rays are diffracted by crystals, into their famous method of interpreting crystal-structures by means of measurement of the intensities of X-rays reflected by crystals at different angles. Within a few years they discovered the fundamental patterns or 'lattices' that determined the form of the chief kinds of crystals, and as time went on they were able in many cases to discover the

exact positions of the atoms in the molecules of chemical compounds—which the chemists had spent a century in deducing by indirect means. They showed the distinction between the structure of bodies ionised in the solid state and those not ionised; and they proved that true salts are completely ionised as solids. Their methods settled the constitution of the oxides. The fruitful conception of the *giant molecule*, the solid whose atoms are linked by chemical forces into a meshwork that continues throughout the whole mass, was a revolutionary and fruitful one. X-ray methods have proved capable of indicating to us the structure of such complex compounds as the silicates, and of many complex organic compounds such as rubber, proteins, synthetic plastics and the like. The electron-diffraction methods, developed by J. M. Robertson and others in recent years, have enabled us to make exact maps of the molecules of organic compounds and proved invaluable in discovering the structure of penicillin. Thus the study of the reflection and diffraction of X-rays and electrons by matter has not only opened up to the chemist fields formerly deemed inaccessible, but has wonderfully confirmed the notions of their structure that the chemists of the nineteenth century had deduced from their reactions and has become a valuable tool for the discovery of the structure of molecules.

The state of 'solution' has received a good deal of enlightenment from British chemists. The diffusion of dissolved substances and the phenomena of osmosis were first studied by Thomas Graham in 1850, and even earlier much attention had been given to their electrical properties. The theory of electrolysis was chiefly developed in this country. Davy's discovery of sodium and potassium in 1807 by passing an electric current through their melted compounds astonished the world, and his work gave a qualitative idea of electrolytic phenomena. Faraday in 1833-4 made the absolutely fundamental researches which led to the precise quantitative laws of electrolysis that bear his

name, and this work was followed up by Daniell, who also (like Grove, Smee and others) invented a useful electrical cell. The practical side of electrolysis, namely electroplating, was developed in the years round 1840 by John Wright and the brothers Elkington.

In the great period of electrochemical research no English chemist attained the eminence of an Arrhenius, Ostwald, or Nernst, though a good deal of valuable work, especially on the hydrolysis of salts, and on conductivities, was contributed by Englishmen: in this connection the work (1910) of Harold Hartley on the conductivities of solutions other than water is particularly notable.

The chemist studies not only solids, liquids and gases, and solutions or homogeneous mixtures of these, but also the heterogeneous mixtures which are grouped under the name of colloids. The study of colloids was initiated by Thomas Graham, the first President of the Chemical Society, in the years 1861-4. Faraday had indeed investigated the brightly coloured gold sols (fine suspensions of particles of gold in water), but Graham first distinguished the class of colloids—substances which in solution diffused slowly or not at all, did not form crystals nor show the definite reactions of crystalline substances of the same chemical class. He introduced much of the terminology we still employ, including the words colloid (*kolla*, glue—the substance Graham considered to be typical of the class), *sol* and *gel*, and he discovered the process of *dialysis*, by which colloids could be purified. We have since learned that colloids are not a class of chemical substances, but rather a state which most, if not all, substances can assume. The importance of colloid studies for biology was clearly understood by Graham. In 1892-5 Harold Picton and S. E. Linder came to recognise the important phenomenon of *electrophoresis*, "the repulsion of a dissolved substance as a whole from one pole to another when we immerse, in the liquid, electrodes connected with a galvanic battery", a process which has proved to be of practical value in many

industrial processes. They likewise grasped the fact that there was a continuous series of grades of solution passing from suspensions through colloidal solutions to crystallisable solutions. The theory of colloids was much further developed by F. G. Donnan and his school who originated the theoretical study of emulsions, which has now been translated into practice in numerous industries concerned with rubber, milk, lubricants, detergents and many other products.

Since 1912 extremely interesting work has been done on mono-layers. In 1912 W. B. Hardy showed that if the 'stray-field' of force from the molecules in a liquid were unsymmetrical a surface skin must be formed having all the molecules oriented in the same way. The Cambridge School under Rideal, and N. K. Adam at Southampton, have made extensive studies of surface pressure and have shown that these films can exist in states analogous to the solid, liquid and gaseous states.

The researches we have hitherto described are concerned with the *structure* of atoms, molecules, and aggregates of molecules—solids, liquids, gases, solutions, colloids; but the most characteristic part of the chemist's work is the study of *chemical change*—the recording and explanation of the manner in which compounds react to form other compounds. This again involves an enormous number of particular researches into the behaviour of every known compound, but nevertheless there are some general principles that apply to all types of chemical change. Much theoretical work has been done on the factors which will increase or decrease the numbers of contacts or collisions between molecules. The effect of concentration or dilution, high or low pressures in gases proved fairly easy to study, but the effect of temperature and of catalysts (bodies present in minute quantities, which alter the speed of reactions without themselves being changed) was a much more difficult task, by no means complete even now. The measurement of the rate at which chemical change takes

place is therefore of the first importance. One of the earliest studies of the rate at which chemical reactions proceed was the researches of A. Vernon Harcourt and W. Esson in 1866, on the reaction of permanganic and oxalic acids, and Sir James Walker's studies of the rate of change of ammonium cyanate into urea (1895-1903) added greatly to our knowledge. The method used by Hartridge and Roughton (1923) for studying very rapid reactions was most ingenious. They chose two reactants which underwent a visible change on combining, and passed them at a known very high speed through two arms of a Y-shaped tube; the extent of their reaction could be estimated by the extent of visible colour change, and the time that change took by the distance along the stem of the Y at which it was apparent. A. Lapworth (1904) and K. J. P. Orton (from 1909) studied the speed of reactions of organic compounds and began the fruitful work of deducing their mechanism from their velocity, work which has since been carried much further by Robert Robinson and others. A. Lapworth, Robert Robinson and C. K. Ingold have investigated organic reactions from the point of view of ionic reaction-mechanisms, while W. A. Waters and D. H. Hey have shown that free radicles or atoms are concerned. Other workers (Polanyi, Hinshelwood) have investigated the nature and magnitude of the forces concerned.

The work of C. N. Hinshelwood, since 1922, on the rate of reaction of mixtures of gases, has been of great importance. He has established the broad validity of the collision-theory of reaction-velocity, formerly held on rather slender grounds; he has shown how the influence of molecular structure, solvent and other features on reactivity could be analysed and interpreted in terms of activation energy and probability factors.*

The phenomenon of catalysis was, from the first, extensively studied in this country. Davy in 1817 and Faraday in 1833 investigated the catalytic action of plat-

* See "Not too fast, not too slow" in *Science News I.*

inum. William Deacon in 1868 discovered the process of making chlorine by the reaction of hydrogen chloride and atmospheric oxygen in the presence of a catalyst; and this catalyst (a copper salt) he selected on theoretical grounds and not, as is usual, by a chance observation. The puzzling effect of intensive drying in inhibiting chemical reactions was first noticed by Mrs. Fulhame in 1794 for the case of carbon monoxide and oxygen, which react with difficulty when dry. This was rediscovered by H. B. Dixon in 1884, and H. B. Baker devoted a lifetime's work (1885-1929) to these phenomena of intensive drying, which still remain obscure. W. A. Bone, from 1902 onward, investigated the effect of surfaces in promoting the burning of hydrocarbons, and so was led to the invention of surface-combustion as a means of industrial heating. Since catalysis is of the first interest both in theory and industrial practice, great attention has been given to it in recent years. The study of the adsorption of gases by solids has proved to be fundamental to these studies.

One of the most important conceptions of chemical kinetics is the chain-reaction,* wherein the reaction of one molecule imparts to another the energy needed to cause it to react, thus giving rise to linear sequences of reacting molecules. The name of Hinshelwood may perhaps be singled out as the leader of the chief school of this type of research.

The effect of light upon chemical reactions was first studied in connection with photography. Thomas Wedgwood and Sir Humphry Davy (1802) produced images on paper treated with silver nitrate, but could not fix them. Niepce and Daguerre, on the continent, showed how to produce permanent photographs, but their methods gave only one picture, and modern photography was initiated by W. H. F. Talbot who produced the first permanent photograph on paper (fixed by concentrated sodium chloride solution). In 1839 William Herschel discovered fixation by 'hypo' and in 1841 Talbot discovered develop-

* See "Chains" in *Science News III*.

ment by gallic acid. Talbot used only waxed paper negatives, but F. Scott Archer in 1846 introduced wet collodion plates, while the dry gelatine films, which have been developed into the modern type, were introduced by R. L. Maddox (1861). The work of F. Hunter and V. C. Driffield (1890) on the speed of plates is well known. Dr. S. E. Sheppard, in 1927, made the important discovery of the 'sensitising specks' on the silver bromide grains in the emulsion, which led to the possibility of producing plates of high and uniform sensitivity. Since 1920 infra-red sensitising dyes have been much developed.

In the field of pure photochemistry, we must note the fundamental law of J. W. Draper (1841) enunciating that only light actually absorbed can produce photochemical action. Much work has been done on the effect of light upon the reaction of hydrogen and chlorine, but some obscurity still remains, after nearly a century of study: and the same may be said of the most important of all reactions, the photosynthesis of carbohydrates by plants, greatly studied by E. C. C. Baly. The chief activity in photochemistry at the present day is the study of the decomposition of organic vapours by light.

The importance of our coal, gas and metallurgical industries has prompted many of our chemists to the study of the combustion of fuel gases. Sir Humphry Davy's discovery of the safety lamp arose from his researches into flame and explosion: Faraday made further contributions. A new era began in 1880 with the work of H. B. Dixon on the rate of explosion and ignition temperatures of various explosive mixtures of gases. A Smithells showed us how to obtain specimens of gases from the interior of flames. The problem of the mechanism of combustion of hydrocarbon gases has been deeply studied by W. A. Bone and his collaborators between 1892 and 1912. H. T. Tizard and D. R. Pye in 1922 did much indeed to clear up the problem of detonation of fuel-gases in the cylinder of the internal combustion engine, but there is here still much

room for investigation. The development of the theory of chain-reactions by Hinshelwood and his colleagues has, however, cleared up most of the difficulties concerning the explosion of mixtures of hydrogen and oxygen and has given us fundamental principles for the understanding of gas reactions. This will lead, we hope, to a fuller understanding of the nature of the reactions in the internal combustion engine.

The results of the investigation of natural products, the preparation of new compounds and the study of their properties has gone on continuously and the results fill thousands of volumes. We can here only note some outstanding researches or groups of researches in inorganic and organic chemistry.

British chemists have not only made important contributions to our knowledge of inorganic chemistry, but were also the founders of the heavy-chemical industry. At the beginning of the nineteenth century Davy's discovery of the alkali and alkaline-earth metals (sodium, potassium, calcium, barium, magnesium) was of fundamental importance. Among a number of nineteenth-century researches, we may note Thomas Graham's work on the arsenates and phosphates as giving us the first clear formulation of the idea of the basicity of salts. B. C. Brodie (the younger) did interesting work (1850-65) on the peroxides and on ozone and proved that the formula of the latter substance was O_3. The work of H. E. Roscoe on vanadium, at about the same period, was a classical piece of research, establishing its true valency and atomic weight, so enabling Mendeléeff to assign it to its true position in the periodic table. The discovery of thallium by Sir William Crookes and his investigation of its compounds was another fine piece of work. Crookes' researches on the rare-earths were valuable also: we have to remember also his discovery of glasses, capable of cutting off both ultra-violet and heat rays, for use by glass workers exposed to fierce heat.

Crookes also played a minor part in the greatest of

British inorganic researches, the discovery of a whole group of new elements—the inert gases, helium, argon, neon, krypton, xenon.

Lord Rayleigh had been attempting to obtain a very exact value for the density of nitrogen and in 1892 he found that the nitrogen he obtained by depriving air of all other known constituents was slightly denser than that obtained from compounds of nitrogen. In 1894 William Ramsay joined in the research and both Ramsay and Rayleigh were successful in isolating from air a new element, a gas of density 20.01, which appeared to be totally unreactive. It was named argon, and Crookes's spectroscopic examination proved it to be a new element or mixture of elements. In 1895 Ramsay obtained a gas from the mineral cleveite, and sent a specimen for spectroscopic examination to Crookes, who identified a yellow line in its spectrum with the yellow D_3 line which Frankland and Lockyer many years before had observed in the solar spectrum and had attributed to an unknown element which they called *helium*, now for the first time discovered upon earth. Ramsay and M. W. Travers then systematically searched for further inert gases, and after 1898, when Hampson's process had made liquid air available, the heavier inert gases krypton and xenon were discovered in the highest boiling fraction, and neon in the lightest. Thus in the six years 1894-1900 there were added to the periodic table five new elements, constituting a group soon to be completed by *niton* (the radioactive emanation), the determination of the atomic weight of which by Whytlaw Gray and Ramsay, using the microbalance, was a triumph of technique.

In the early twentieth century the principal field for new work was the investigation of the chemistry of the radio-elements, carried out in this country by Rutherford, Soddy and others. After the Bohr theory of the atom had thrown so much light on problems of valency inorganic chemistry was largely directed towards the study of the

covalent and co-ordinated compounds of the metals, and the space-relationships of their compounds. The most recent development of all is the production of new elements and isotopes by bombardment of elements with neutrons or other particles, but this so-called *nuclear chemistry*, which culminated in the triumph of nuclear fission and the synthesis of several new elements, such as neptunium and plutonium, is really a branch of physics, though chemistry has played an indispensable part in the separation of the new elements from the parent mass.

So much for the field of pure inorganic chemistry; we must now pass to a brief survey of the British heavy-chemical industry. This industry began well before the period of modern chemistry. Ward and Roebuck founded the sulphuric acid industry in the eighteenth century: later came Hill's substitution of pyrites for sulphur, thereby further lowering the price of the acid. Charles Tennant's invention of bleaching powder increased the demand for chlorine and thereby for sulphuric acid. The Leblanc process for making soda, though first brought into use in France, was chiefly developed here, and led to the invention of several processes for disposing of its waste products. William Gossage (1835) began the conversion of the waste hydrogen chloride into hydrochloric acid and William Deacon (1868) showed how to convert it into chlorine. Very important also was Weldon's method (1868-70) of recovering the manganese used in the manufacture of chlorine. The treatment of the other by-product, alkali-waste, was made possible by A. M. Chance's process for recovering sulphur from it. Despite these improvements and economies the Leblanc process had to give way to the Solvay process, which, although a Belgian invention, was largely perfected in this country by Ludwig Mond, who in the course of these researches invented the Mond producer, and was led to the discovery of nickel carbonyl, which could be used to separate pure nickel from all other elements—so founding another industry.

Returning to the manufacture of sulphuric acid, we must note the invention of the Glover tower (1859) which further brought into practical use the Gay-Lussac towers invented in 1827. Meanwhile Peregrine Phillips in 1831 invented the 'contact' process, though it was not till 1875 that W. S. Squire and R. Messel made it capable of industrial application.

Many industries must be left almost unnoticed in a brief survey, but the work of Accum and others (*c.* 1819) on the recovery of ammonium salts from ammoniacal liquor of the gas-works was the first step towards the fertiliser industry that developed from it late in the nineteenth century. The real founder of this industry was J. B. Lawes, who invented superphosphate in 1842 and thereby again increased the demand for sulphuric acid. The Portland cement industry was also developed in this country by a number of inventors and manufacturers.

Some of our greatest discoveries have been in metallurgy, We may mention the cyanide process for separating gold, and the processes of Parkes and Pattinson for separating silver from lead. But by far the greatest were the researches that have led to improvements in the manufacture of iron and steel. Though these belong as much to engineering as to chemistry we must remember the names of Bessemer, Siemens, Gilchrist and Thomas, Hadfield, Roberts-Austen and other metallurgists as founders of our modern industrial developments.

Between 1750 and 1880 Britain was the leader in the heavy chemical industry, but in the years 1880-1914 she fell behind. In the last thirty years, however, the chemical industry has taken a fresh start and the British chemical industry is the most important in the eastern hemisphere.

This defection and revival is even more noticeable in the field of organic chemistry.

Some of the earliest British work on organic chemistry was important as throwing light on the problems of valency and atomic weight. Such was the work of Williamson on the

constitution of alcohol and ether, and Frankland's classical researches on the organometallic compounds. The work of Couper has already been mentioned as contributing to the idea of graphic formulæ: and the work of Alexander Crum Brown in proving the equivalence of the four valencies of carbon was an essential step towards modern organic chemistry. Kekulé's discovery of the ring-formula for benzene was made in England—on the top of a bus, we are told—and W. H. Perkin's synthesis of hexahydrobenzene from hexylene bromide and sodium was a strong piece of evidence for it.

It may be said that in the nineteenth century organic chemistry was more cultivated on the Continent than in England, though we can record a number of pieces of work, such as Frankland and Duppa's famous acetoacetic ester syntheses and W. H. Perkin's fundamental work on the aniline dyes. In late years, however, and especially since 1920 there has been a great revival of organic chemistry, so much so that the greater part of the Journal of the Chemical Society is devoted thereto. It is impossible indeed to do more than allude to some of the main trends.

On the theoretical side, the influence of groups of atoms already attached to the benzene ring upon the position of attachment of other groups added to the ring later, has been much studied in this country, *e.g.*, by H. E. Armstrong (1887) and later by Crum Brown and Gibson, whose well-known rule (1892) predicted the true results in a majority of cases. Since that time a mass of most important work concerning the mechanism of organic reactions has been done, and Lapworth, Lowry, Robinson and Ingold, between 1920 and 1926, initiated the electrochemical theory of the course of organic reactions. They envisaged a drift of electrons to one end of a molecule, caused by induction and also by another effect, the electromeric. This drift activates or deactivates the aromatic nucleus (the benzene ring), the attacking reagent seeking the point of high electron-density. The electromeric effect, mentioned

above, proved to be in remarkable consonance with physical studies of resonance. This work has explained a great number of organic reactions which had never been satisfactorily accounted for. The work of Thorp and Ingold on tautomerism, of C. A. Waters and his school on free radicles, and the work of Sidgwick and his school on the apparent cases of bivalency of the carbon atom have, indeed, gone far to remove the anomalies of classical organic theory.

Much work and ingenuity and imagination have been expended on unravelling the structure of natural organic compounds. The group of *terpenes* (including many perfumes, essential oils, and also rubber) were investigated by W. H. Perkin (jun.) and by William Tilden, the first to synthesise rubber. The *alkaloids* were also investigated by Perkin, but the pre-eminent work in this field is that of Robert Robinson. The chemistry of the *carbohydrates* has been largely elucidated in this country. The work of C. F. Cross and E. J. Bevan on cellulose led to the discovery of viscose, chief source of artificial silk. T. Purdie, J. C. Irvine, W. N. Haworth and E. L. Hirst have carried on the tradition begun by the methylation technique of the first-named and have transformed this difficult branch of organic chemistry. Some progress, largely through X-ray methods, has been made towards the investigation of the *proteins*, the material of life, but there is still a great deal to be discovered in that field. The *natural colouring matters* of plants have been successfully investigated, chiefly by Robinson. The *vitamins*, of which the discovery was due in a large measure to the pioneer researches of Sir Frederick Gowland Hopkins, have received a great deal of attention. The D group of vitamins and certain of the hormones belong to the group of *steroids* which have presented particular difficulties in their investigation, largely overcome by Heilbron, and by Robinson and their schools. We may mention here the remarkable work of Harington in synthesising the active principle of the thyroid gland and

the great work done at Oxford and elsewhere in the investigation and attempted syntheses of penicillin by the team of workers headed by Sir Howard Florey.

The British organic chemical industry was founded, we may think, by W. H. Perkin, who, in 1856, when only eighteen years of age, discovered the famous dye, mauve, and set up the first synthetic-dye works. In 1869 he synthesised alizarin, the active principle of madder. In the period between 1856 and 1887 British chemists and firms initiated a great number of important dyestuffs and groups of dyestuffs, but from the eighteen-eighties onward Germany captured more and more of this industry. Moreover, since the same kind of equipment and personnel is needed for the synthesis of drugs as of dyes, the new synthetic-drug industry which began in the eighties was almost entirely German. The war of 1914 gave us a rude awakening. It was necessary to build up a fine-chemical industry at short notice, and between the wars it was not allowed to lapse. Such remarkable dyestuffs as caledon jade green, phthalocyanine, and the aminoanthraquinone dyestuffs for acetate silk have been discovered and produced in this country.

The British fine-chemical industry has contributed splendidly to the conquest of disease. The production of synthetic vitamins is an example, but the greatest has been the investigation and production of the chemotherapeutic agents such as sulphapyridine, sulphathiazole, sulphadiazine and most recently penicillin. Rarely can any industry have saved so many lives.

Mention must be made of the production of plant-growth substances, selective weedkillers, and such insecticides as gammexane, which have proved invaluable in horticulture.

Finally we are to admire the new and flourishing plastic industry, first developed in the U.S.A. and on the continent, to which the research workers of Imperial Chemical Industries have made remarkable contributions, such as perspex and polythene, and further developments are to be expected.

Never, we may think, has British Chemistry, pure and applied, been in so thriving a state, and, given the means—men and material—it must prove to be among the greatest of our national assets.

GLOSSARY

AURA: The first symptoms heralding the onset of a fit, e.g., an unpleasant sensation of smell.

CRITICAL STATE: A gas or vapour can often be liquefied by compressing it; thus liquid air is made. But above a certain temperature, characteristic for each gas, this is no longer possible, and no amount of compressing will liquefy it as long as it is hotter than this critical temperature.

DETERGENT: A soap or any other substance which lowers the tension between oil and water (or any other two phases) and permits them to mix.

DIALYSIS: Sheets of material such as cellophane, or other membranes such as sausage-skin, dried pig's bladder, etc., have such very fine pores in their substance that they will let small molecules through, but offer a complete barrier to large molecules, which are too big to get through the holes. This provides a way of sorting out molecular sizes, getting the big molecules pure of the small ones. The mixed solution is placed in a closed bag of a membrane and immersed in running water; the small molecules wander out into the water and are carried away, the large ones are held behind in the bag.

ELECTRON DIFFRACTION: Although electrons are several thousand times smaller than atoms, and atoms themselves "empty space" inside, and spaced apart at regular intervals in a crystal, a beam of electrons does not pass straight through a solid and emerge unchanged the other side, but is bent and scattered in various directions in a manner reminiscent of the glistening of a spider's web in sunlight. From measurements of the intensity and direction of electron scattering, deductions can be made of the arrangement of atoms in a crystal, since the diffractions depend on the interatomic spacings.

OSMOSIS: The "attraction" into a semipermeable bag (as in Dialysis, q.v.) containing large molecules, of water or other solvent, which tries to dilute the contents to bring them to the same strength as the pure solvent outside.

PSYCHIATRY: The study of mental illness, as distinct from Psychology, which is the study of normal mental processes. Mental diseases are often divided into two groups: *neuroses*, in which the illness upsets only a part of the sufferer's life and he is aware of his abnormality; and *psychoses*, in which the illness pervades and distorts the whole personality in a way the patient is quite unaware of—what is commonly called madness or lunacy.

Psychoses may commence as the sequel to infectious disease or brain damage (from drinking too much alcohol, for example), or be completely brought on by worries and other mental or *psychogenic* causes. They are characterised by various collections of symptoms.

Hallucinations are false sense perceptions, for example hearing voices speaking in one's ear, though one is alone and in silence.

Delusions are false beliefs which cannot be shaken, no matter how much indubitable proof and demonstration to the contrary be offered.

Obsessions are ideas or delusions which take possession of the mind to the exclusion of all else—for instance, a man who imagines that he is surrounded by spies, that everyone is watching him, that every harmless passer-by is a member of the secret police.

It is difficult to discern amidst the varying combinations of symptoms that mental patients show whether there are any truly distinct diseases. However, most authorities recognise the division into schizophrenia and manic-depressive insanity, and some add further distinct varieties such as *Melancholia* (profound depression, often with delusions) and *Dementia* (progressive deterioration and loss of intellectual power—reasoning, memory, will, with insanity), which others regard only as symptoms.

Schizophrenia is characterised by a withdrawal from the real world into a dream world of one's own imagining. All emotional response to other people is lost, and the sufferer's laughter and tears relate only to events in his dream. He lapses into silence, no longer listens when spoken to, does not reply, may smile suddenly to himself, and sit for long periods staring into vacancy, apparently doing nothing. There are many forms of schizophrenia, classified according to the predominant symptom. *Catatonia* is a form in which the patient becomes melancholic and stupid, and stands for long periods motionless in one place, or will even passively hold any statuesque pose one cares to arrange him in. Schizophrenia usually gets progressively worse.

Manic-depressive insanity, on the other hand, is an illness of excessive emotion which comes in waves or cycles. Periods of extreme excitement (*mania*) alternate with periods of normality or profound depression. In other words, there is a disturbance of emotion or *affect*, and this is therefore an *affective psychosis*.

Most psychotic symptoms are only gross exaggerations of characteristics found in all normal people. The diagnosis of mental illness is a specialist's job, and this brief account is intended only as an introduction to the technical terms of the subject and may prove most misleading if used as part of a "Home Doctor".

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About Our Contributors

A. W. Haslett is a Cambridge graduate, who has made scientific journalism his career. He is the Editor of *Science Today*, and author of a number of books of which *Science in Transition* has lately been recommended by the Book Society.

C. S. Jones has been engaged in industrial science for upwards of thirty years, and is a contributor to various technical journals.

Eric Kraus—Czech born—a chequered school and university education in Bohemia, Switzerland and Paris—spent four years with a Czech exporting firm travelling widely all over Europe including Russia and Middle East—abandoned business career to study Science at Prague's Charles University, and later in Norway—served with R.A.F. and is now working with Australia's Council for Scientific and Industrial Research. Likes ski-ing, sailing, flying when he finds the opportunity.

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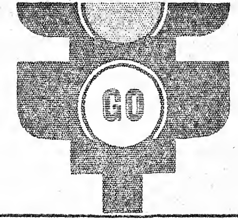
Mario Pavan—Assistant Professor of Zoology at the University of Pavia (Italy). A keen professional speleologist, and editor of *Scienza e Lavoro*, an Italian monthly of popular science.

J. H. Quastel, F.R.S.—1924—Elected Fellow of Trinity College, Cambridge, for research work in biochemistry: 1927—Awarded Meldola Medal by Royal Institute of Chemistry for chemical research: 1929—Appointed Director of Research, Cardiff City Mental Hospital: 1940—Elected Fellow of Royal Society: 1941—Appointed Director of Agricultural Research Council Unit for Soil Metabolism: 1947—Appointed Professor of Biochemistry at McGill University, Montreal, Canada, and Associate Director of the Institute for Research in Cell Metabolism at Montreal.

Gabriele Rabel, studied Physics and Biology at various universities including Vienna, Leipzig and Berlin.

W. A. H. Rushton is a Fellow of Trinity College and lecturer in the Cambridge Medical School where he was educated. His research has been chiefly upon the theory of nerve excitation.

F. Sherwood Taylor, born 1897. Original subject Chemistry, on which he has written numerous well-known text-books from 1931 onwards. Research into the history of the subject since 1926, and into the general history of science since 1930. Numerous papers on the history of alchemy and early chemistry. Editor of the Journal *Ambix*. which is devoted to these subjects. Various works on the history of science including *Short History of Science*, 1938, and *Science Past and Present*, 1945. Since 1940, Curator of the Museum of the History of Science, Oxford, and responsible for the teaching of the history of science at that University.



NAVIGATION ON THE ROAD?

When the *Queen Mary* enters a busy port, she and all the other vessels obey the recognized lights and signals on which safe navigation depends.

We, too, obey lights and signals — and rely on them for safety — when we drive or ride or walk on the roads.

We are, in fact, "road navigators." Modern traffic simply could not work without a set of rules which we all accept.

Why, then, are there still accidents — far too many?

Partly because we don't all know and understand the rules and principles of Road Navigation. And even if we know them, we forget or ignore them. And partly because some of us don't yet realize that the rules apply to *everyone* — walkers as well as cyclists and drivers. *Any* of us can cause an accident in which we or other people get killed or maimed.

If we all understood the principles of good Road Navigation (based on the Highway Code) and obeyed them *all the time*, traffic would flow faster and more smoothly. We should all get about more easily and, above all, *more safely*. By learning to be skilful Road Navigators, we can help ourselves and everyone else to *get home safe and sound*.

GET HOME SAFE AND SOUND

Issued by the Ministry of Transport

SOME NEW AND FORTHCOMING TITLES

SCIENCE AND THE NATION

By Members of the Association of Scientific Workers

How scientific knowledge can be used to increase efficiency, and research planned to obtain new knowledge in fundamental and applied science.

Among the topics dealt with are:

SOME ASPECTS OF BRITISH ECONOMY
KEY INDUSTRIES OF BRITAIN: FUEL AND POWER, HEAVY CHEMICALS, ENGINEERING AND COMMUNICATIONS, AGRICULTURE
INDUSTRIES OF THE FUTURE: PLASTICS AND FERMENTATIONS
HEALTH AND THE MEDICAL SERVICES
FOOD AND CONSUMER GOODS PROBLEMS
BUILDING AND HOUSE DESIGN
CONSUMER RESEARCH
PROBLEMS IN ADMINISTRATION
THE FUTURE OF FUNDAMENTAL RESEARCH
THE PLANNING AND FINANCE OF SCIENCE
FACILITIES FOR RESEARCH
SCIENCE AND CULTURE
SCIENCE IN GENERAL EDUCATION
THE TRAINING OF SCIENTISTS
SCIENCE IN RECONSTRUCTION
THE POLITICS OF SCIENCE

THE WORLD'S WEALTH

W. G. Moore

This book is not about money; it is about wealth. Its first aim is to describe just where the world's wealth is located, just where the goods that we all need in varying forms and quantities are produced. It also relates how and where these goods, constituting our food, drink, clothing, fuel, shelter, and other necessaries of life, after being gathered, grown, raised, or extracted in their raw state, are converted into the shape in which we consume them, into usable commodities. Then it tells of the means by which they are transferred from producer to consumer, the principal highways of transport, by sea, land, and air.

The chapter headings—"The Harvest Of The Sea," "The Cups That Cheer," "King Cotton"—are enough to show that it is not a formal text-book, though due emphasis is placed on the geographical and economic factors influencing the production and distribution of the world's wealth. By examining these factors, the book seeks to explain, too, some of the economic problems of our age: to an Englishman, for instance, not only *where* his bread and butter come from, but *why* he must buy them abroad; not only *where* his coal is mined, but *why* coal determines his own and his country's prosperity.

Its last chapter summarises what must be, from the viewpoint of the "2,000 million consumers" of the world's wealth, the most acute of all problems: the existence of dismal poverty among so many, side by side with enough potential wealth to satisfy all.

A Pelican Book

(A173)

SCIENTIST IN RUSSIA

by Eric Ashby

In 1944 the Australian Government, on the initiative of the Minister for External Affairs, decided to send a scientist for a year to the Australian Legation at Moscow. It was Mr. Ashby's good fortune to be selected for this mission.

In addition to the technical information which he sent to his Government in official despatches, he collected a great deal of other information of interest to scientists, to educationists, and to the general reader. This unofficial account of his visit contains that material, and embodies the results of his visit which he was not obliged to embalm in his mimeographed reports.

His book tells how scientific research and education is organised in the U.S.S.R.; of the relations between the scientists and the Government and State authorities: of the public attitude to scientific work: and contains among other good things a very human and amusing account of a journey to the Far North.

Everyone who is interested in the scientific work which is being carried on under the auspices of the Soviet Government will find much material in this book of the greatest importance. It will be of special interest to all concerned with education, by reason of the very full information it provides on the organisation and syllabuses of schools, colleges and universities and other higher educational institutions.

A Pelican Book
(A186)

THE INVENTOR AND HIS WORLD

by H. Stafford Hatfield

Inventors of genius, partnered by industrialists whose pride was in the excellence of their product rather than the magnitude of their dividends, made Britain the pioneer of industrialism. Up to 1880, all the world turned first to Britain when in search of the latest and best. We lost that proud place to others, not because our inventive genius petered out, but because the control of our resources passed from men with pride in technical excellence to financiers who serve the interests of their shareholders.

This book is a survey of the whole field of invention, which, as everyone now realises, we must cultivate intensely or perish. We cannot earn our living, as we conceive living, by mass production of standard articles. We must earn the wages of high skill, turning a shillingsworth of raw material into a poundsworth of goods unobtainable elsewhere. All experience shows that such goods are created by individual inventors, who have found this country very unreceptive in recent times. This book is addressed to such men, to explain them to themselves and to the public at large, more particularly the manufacturers who find them difficult, and the legislators who have failed to create a patent law which ensures them a due reward under modern conditions. Nationalisation of industry creates a new and hopeful situation for the inventor, since pioneer invention, so often a dead loss for one firm after another till technical success is attained, is now a business which, if properly pursued, will benefit the industry as a whole.

A Pelican Book
(A178)

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Edited by Edward Crankshaw

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One shilling per issue

SCIENCE NEWS

VI

Science News

VI

PENGUIN BOOKS

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ACKNOWLEDGEMENTS

We wish to thank Glaxo Laboratories Ltd., of Greenford, Middlesex, for permission to reproduce plates 13 to 22 showing the production of Penicillin, and the Central Office of Information for providing plates 1 to 4 on the Antarctic.

CORRECTION

In a note on partition chromatography (S.N.4 page 67) the method is described as due to Dr. Martin and Dr. Synge of the Lister Institute. Dr. Martin is actually working on behalf of the Wool Industries Research Association, Leeds, who financed the research, and we apologise to them for omitting mention of their name.

Editorial

What is News, speaking scientifically? Newspapers, which rarely have any inkling of science, love Truth Drugs and Death Rays and two-headed calves; or the latest experiment on chilblains or cancer which they can blare out as *The* Cure. If they are not sensational, they usually offer instead a little pellet of undigested facts and figures which persist without meaning in the reader's head: the horse-power of a new engine, or oil production last year, or the number of hairs on a bee's wing. It is obvious indeed that the place to look for the latest discoveries in the scientific world is not in the pages of a newspaper—for the simple reason that most journalists never have any scientific knowledge to help them understand and assess this kind of news, and are therefore bound to blunder. The only place to look is in the pages of a learned journal, written by scientists for scientists and consequently not the safest spot for the novice to linger in unguided. We draw our material from these journals, and try to act as some kind of guide by applying standards of selection. Our experts try to assess the trustworthiness of the information published before passing it on. Sometimes they wait a year or two, to see if a discovery boldly announced is confirmed as correct by subsequent events. For speed and hurry have no place in scientific news. All one sweeps up in a scoop is red herring.

In our view scientific news is of three kinds. Partly it is a summary of what scientists are thinking and talking about just now, what's cooking in the Labs., what subjects they are investigating, *not* the detailed results of that investigation. Here it is the current atmosphere, the scientific weather, that we are out to report, and that is the function of articles such as "Physics Front" by A. W. Haslett.

Sometimes a particular problem or subject is worth a more extended analysis. In "Problems of Nuclear Physics", Prof. Peierls sets out to show what aspects of the nature of matter are engaging the attention of physicists to-day. Atomic energy and the atom bomb are engineering topics now, have passed out of the hands of fundamental physicists. They are primarily interested in the next term of the analysis of matter in the sequence "Matter is composed of atoms which are composed of electrons and nuclei which are composed of . . ." And their interest is a second kind of reporting.

But thirdly, and most important part of all in science news, is the pause to look back over the last few years, to collect up the facts and ideas which have become established, to see how far we have now progressed in this field of research or that, where we stand at the stocktaking. Articles like "Glaciers", "Diatoms", "Making Penicillin" attempt this function of review. They are not last month's or last year's discoveries, or even the results of the last five years' work. Nor do they contain the last words on their subjects. They are attempts to make the reader aware of the present state of knowledge so that he can be ready to assimilate the next step, or even perhaps make that step himself.

Turn the page, and see our policy in practice.

Report on Antarctica

BY DR. GABRIELE RABEL

1. INTRODUCTION: EARLY EXPEDITIONS

It is surprising to hear that thirteen nations in recent years have been arranging, or planning, expeditions into the remote, ice-bound and barren south polar regions—more surprising still to learn that this zeal is partly due to a political motive, the desire to secure a slice of this unpalatable ice-cake. Why? No one knows. So far there is little indication of the presence of uranium or other heart-stirring mineral wealth waiting to be brought to light. It makes me think of a woman who joins a queue without knowing what she is queuing for. Several countries look back on a century of antarctic discovery and research, but the interest of others is of quite recent date.

At present, the political divisions on the map are as follows:

There is a British sector called the Falkland Islands Dependencies, situated in West Antarctica (20–80° W), nearest to South America. It includes South Georgia and the S. Sandwich Islands which Captain Cook discovered in 1775, also Desolation, Deception and the New Shetland Islands where Edward Bransfield sent out boats in 1819, that he "might plant the Jack and take possession of the land in the name and behalf of H.M. George IV, his heirs and successors." Bransfield, it is true, "had very faint hope of ever being able to speak well of its fertility", but his party noted "a beach with seals so stowed in bulk that it seemed dangerous to approach them", which suggested "a lucrative trade in these creatures of great size, full of oil, with the finest furs", the shores crowded with penguins

"disputing possession with the human visitors, who could not advance until a great slaughter was made and a lane cut through them", "immense shoals of sea elephants asleep", and "numerous whales, but excessively lean and poor."

Seal and whale hunting was mainly responsible for the first exploration of the antarctic regions. A sealer from Connecticut, Mr. Palmer, visited in 1821 what the Americans call now the Palmer Archipelago and the Palmer Peninsula. A famous London whaling and sealing firm, Enderby Brothers, encouraged its masters, including Briscoe, Balleny and Weddell, whose names we also find on the map, to explore the southernmost waters.

Graham Land, all the islands around, and on its eastern side the mysterious Weddell Sea and Coates Land are within the British sector. Then, to the east, there is a Norwegian sector called Queen Maud Land.

Further east again there is a very large Australian sector, the scene of Sir Douglas Mawson's labours and, cut out of it, a strip of French territory called Adélie Land nearest to Tasmania. This was annexed only in 1924, but first visited by the Frenchman d'Urville in 1840. Of other French expeditions the best known are those of Dr. Charcot, son of the celebrated physician, who cruised between 1903–1913 in his ship "Pourquoi pas?" on the west coast of Graham Land and discovered Charcot Island.

The turn of the century ushered in a series of purely scientific journeys, not followed by any annexation claim. From Belgium sailed the "Belgica" under Captain de Gerlache with Amundsen and Dr. A. F. Cook on board. From England sailed the "Discovery" under Commander Scott with Lt. Shackleton and Dr. A. E. Wilson on board. From Sweden sailed a party under Dr. Nordenskjold. From Germany came the ship "Gauss" built by the German Government for the purpose, under Professor Drygalski, who named a mass of volcanic rock the "Gaussberg" and a stretch of land "Kaiser Wilhelm Land". Drygalski and Scott co-operated in their magnetic and meteorological

observations. Another German, Professor Filchner, penetrated deep into the Weddell Sea and tried to survey what is now called the Filchner Ice Shelf. Many may still remember the dramatic contest for reaching the South Pole. Shackleton (1907) desired to discover both the magnetic pole, which he did, and the geographic pole, which he nearly did. When Scott set out in 1910 with a large staff of scientists, his main objective was to reach the pole. But to his dismay, he found that Amundsen had been there a month before, on December 14th, 1911. Scott, with four others, including Dr. Wilson, the chief scientist, died a horrible death from exhaustion and cold.*

An expedition of another type was sent out in 1938 by Herr Goering. The members alighted only on the edge of an ice shelf, but they took very interesting photographs from the air, and they circumscribed a bit of Lebensraum (in the western part of Queen Maud Land) which they called "Neu Schwabenland", by dropping around it flags attached to arrows.

The Argentine Government, which has maintained a meteorological station in the S. Orkney Islands since 1903, when the Scotsman Dr. Bruce installed it, bases a claim on this fact, and its geographical proximity. Chile, by a pronouncement of 6 November, 1940, simply "decreed that all lands, islands, reefs, glaciers . . . in the sector between 53° and 90° W. constitute the Chilean Antarctic."

Peculiar is the political attitude of the United States. American merchants such as Mr. Palmer were among the antarctic pioneers. In 1839, the U.S. Navy despatched Comm. Wilkes on a voyage of discovery round the world, and cruising towards the south pole, he saw land "and gave the land the name of Antarctic Continent." A century later occurred the well-known private enterprises of Admiral

* Thirty miles from the pole, Scott wrote in his diary: '. . . the only appalling possibility is the sight of the Norwegian flag forestalling ours,' and three days later at the pole: 'Great God! this is an awful place, and trouble enough for us to have laboured for it without the reward of priority.'

Byrd and Mr. Lincoln Ellsworth, and in 1939 the "Antarctic Service Department" of the U.S. Government arranged an expedition under Byrd's command which was prematurely called off in December, 1941, after Pearl Harbour. Rear-Admiral Byrd explains that the U.S. "wanted to know especially the hitherto unknown sector in which the extreme south-eastern part of the Pacific Ocean abuts on the continental landmass of Antarctica. Great Britain, Australia, France, Norway claim sovereignty over parts of Antarctica. We must be prepared with information . . .".

Byrd and his men did not fail to erect cairns and hoist flags, but so far the U.S. Government, while "reserving its rights", has acknowledged no sovereign claims in Antarctica, whether raised by foreign governments or by its own citizens.

In the winter (southern summer) 1946-7 the U.S. Navy dispatched another expedition, 4,000 men, again under Byrd's command, "Operation Highjump", with the task of training both naval and air forces for operating under polar conditions, to practice the technique of erecting bases and to test scientific instruments at extremely low temperatures. The last American expedition had considerable trouble with their instruments, even cameras refused to work at temperatures which went down to minus 72 degrees.

Proceeding now to recent British activities, we must not forget a small scale expedition to Graham Land in 1920-22. It consisted in the end only of two men, Bagshawe and Lester, to which, however, Byrd paid the tribute that "they collected more data per man than have been collected by the members of any expedition before or since."

A larger party went out under Mr. John Rymill, an Australian sheep farmer, in 1934. Its proper name is "British Graham Land Expedition 1934-37", but I beg leave to call it for brevity's sake "The Grahamers", as I shall for the same reason designate the "U.S. Antarctic Service Expedition 1939-41" as "The Byrdians".

Graham Land and the islands around have been

visited every summer by the ships "Discovery II" and "William Scoresby," directed by the joint British—Australian—New-Zealand Discovery Committee under the Colonial Office. They studied in a most comprehensive way the distribution of marine life in relation to depth, water currents and all the other physico-chemical conditions of the water. One of their main activities is the marking of whales. A stainless steel dart, fired from a gun into the blubber of the whale, has imprinted on it a number and a promise of reward for return with an account of where and when found. One dart was returned ten years after firing and 2,000 miles away. In due course, this method should yield ample knowledge about the migrations of whales.

From 1939 to 1943 the ships were used for war purposes, and in 1943 a new scheme of investigation was started which is more concerned with the land than with the sea. Its full title is "The Falkland Islands Dependencies Survey", officially abbreviated to F.I.D.S.

The scheme consists in having permanent bases and a regular service for relieving the men and refilling the stores, for a man cannot stay more than a year or two in "those dreary parts", and if he must return before reaping the harvest of his labours, this harvest may easily be lost. Since 1943, such a regular relief service has been carried through. When the war was over, Commander Bingham, who had accompanied earlier expeditions as a surgeon became commander of F.I.D.S. At first this scientific survey had to be treated as an "operation" under the code word Tabarin. The scientists were delighted when the spurious secrecy was abandoned.

One writer expresses anxiety because the great number of polar expeditions, not all of scientific importance, has damped the interest of the general public and such generous donations as in earlier times are no longer forthcoming. Indeed, the Grahamers had a surprisingly small sum at their disposal. Therefore well-trained scientific specialists had to do all the menial work. Even the ship's crew con-

sisted of scientists, and they had a tough job with their "Penola", a retired Breton fishing boat which soon developed engine trouble and had to travel under sail alone for hundreds of miles. Surprisingly, the Byrdians, though their official grant was vastly larger, complain too about having to drop some of their aims for want of money and about the necessity of unloading sledges, building houses, training dogs, repairing clothes and machinery which impaired their scientific work. There are no natives in Antarctica whose services can be enlisted!

For the last twenty years the centre of all polar activities in Britain has been the Scott Polar Research Institute in Cambridge. It was founded in 1926 and moved in 1934 into a building of its own, a building on a fine site, pleasant to look at and dignified. Owing to rich gifts of pictures and books, the house is too small already.

First director was the geographer Professor Frank Debenham. He retired in 1946 and was replaced by the Reverend W. L. S. Fleming, Dean of Trinity Hall, a geologist and glaciologist who was one of the Grahamers and took part in other expeditions. The Committee of Management is a University body, but the Royal Geographical Society nominates one member.

Dr. H. R. Mill has transferred to the Institute his valuable Antarctic book collection, Dr. Wilson's water colours are also there, further manuscripts, records, maps, samples of polar equipment, etc.—the task of the Institute being to collect all possible information about polar matters and to make it available to all who seek it. During the war, Government Departments and private industrial firms consulted the experts about cold weather clothing and equipment, and how to make and pack things destined to endure extremely low temperatures.

One way of spreading the acquired knowledge is the *Polar Record* which appears normally twice a year. The present article owes much to the *Polar Record* as well as to personal information by Mr. Fleming.

2. THE TECHNIQUE OF POLAR TRAVEL

Weather and Acclimatisation

Every description of antarctic journeying abounds with complaints about the weather which assures safe travelling, even in the short summer season, for only a few days. Here is what the Byrdians say about their East Base: "If there were light westerly winds, low clouds and fog would lie for weeks over the ground ... When winds were from the east or south, the sky was clear and it was necessary to seize the opportunity for a flight quickly, because as the air poured down the coastal passes from the plateau, the velocity at the base built up dangerously. There were only elusive periods of suitable flying weather." And imagine what this constant "poor visibility" means for sledging parties for whom an abyss may wait just round the corner. Sir Douglas Mawson describes "drifting snow which poured fluid-thick over the landscape; for many days it was impossible to see one's hand held at arm length. Such weather lasted almost nine months."

Blizzards may break out suddenly with tremendous violence and cease just as abruptly, but winds of two miles a minute have been recorded as lasting for many hours. It is not so much the cold which causes pain as the wind.

The temperature, especially on the Ross Ice Shelf, frequently dropped to seventy degrees or more below freezing point. Two of the Byrdians, P. Siple and Ch. Passel, established that the sensation of cold and heat, and hence the feeling of comfort, does not depend on the absolute temperature of the skin but on the rate at which it loses heat to the surroundings. Touching metal or snow with bare hands burns the flesh like a hot stove, because these objects carry the heat away so rapidly.

Siple and Passel measured the time needed for a quantity of water to freeze under varying conditions of wind, etc., and built on their results a formula as well as a gadget called the "Relative Comfort Thermometer". If the wind

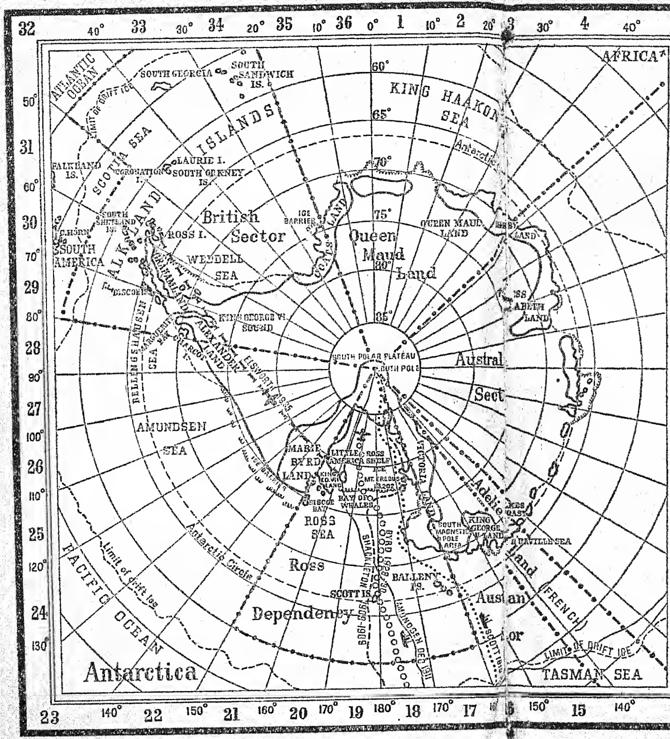
AFRICA
ATLANTIC OCEAN
LIMIT OF DRIFT ICE
SOUTH GEORGIA
SOUTH SANDWICH IS.
KING HAAKON SEA
ISLANDS
SCOTIA SEA
FALKLAND IS.
LAURIE I.
CORONATION I.
SOUTH ORKNEY IS.
SOUTH SHETLAND IS.
C. HORN
SOUTH AMERICA
ROSS I.
British Sector
ICE BARRIER
Queen Maud Land
QUEEN MAUD LAND
WEDDELL SEA
KING GEORGE VI. SOUND
ALEXANDER LAND
CHARCOT I.
SOUTH POLAR PLATEAU
SOUTH POLE
Austral
Sect
AMUNDSEN SEA
MARIE BYRD LAND
LITTLE AMERICA
ROSS SHELF ICE
KING ED. VII LAND
MT. EREBUS 13,202
BAY OF WHALES
ROSS SEA
VICTORIA LAND
Adelie Land
SOUTH MAGNETIC POLE AREA
KING GEORGE V. LAND
Antarctic Circle
Limit of drift ice
PACIFIC OCEAN
Ross Dependency
BALLENY IS.
SCOTT IS.
BYRD 1929
AMUNDSEN DEC 1911
SCOTT 1912
FRENCH
LIMIT OF DRIFT ICE
TASMAN SEA
Antarctica

Fig. 1. The South polar end of the Earth. The *geographical* south pole lies right in the centre of the map, and the *magnetic* South pole is about 1,300 miles away (to the North of it) near the edge of the Antarctic Continent in sector 16, the Australian sector. To get some idea of the scale, find Cape Horn, the southernmost tip of South America in sector 30; it is approximately 2,500 miles from the Pole as the crow flies. Another indication of size is that the British Isles, drawn on the same scale, would fit very easily inside the innermost circle (Latitude 85°S) round the pole, with plenty of spare room.

A similarly-drawn view of the North Pole would look totally different: there is nothing but sea, frozen or otherwise, within the circle of 85° N, surrounded at varying distances out to the Arctic circle by land masses. Three-quarters of Greenland, for instance, lies between Lat. 85° and the Arctic circle, while the coast-line of Siberia is mostly between 50° and 60° N. If they were transferred to the same latitude south, they might come alongside Cape Horn, or absorb South Georgia, and would be mostly within the limit of the Southern Drift Ice.

Alexander Land is now known to be an island of only small extent, since King George VI Sound bends round northwards into the sea near Charcot Island.

velocity increases from zero to 20 miles an hour, the rate of cooling increases by 75 per cent, but above this velocity cooling does not increase, and in a gale the temperature even rises.

Heat loss by respiration may be 54 calories per day in the tropics, but 270 in very cold climates, for the incoming air must be warmed by 30–40 degrees in the lungs, as well as saturated with water as it is excessively dry.

Fatigue develops less quickly in cold climates than when the body is overheated by perspiration. Like a mechanical engine, the body seems to work best when the heat is rapidly carried away.

The first year the men wore their heaviest clothes and shivered in summer. The second year they worked stripped to the waist at 0° C.

There is no flu or other disease carried by germs in the Antarctic, but frost bites seem unavoidable when "fiddling" with apparatus outside. The worst for the Byrdians was toothache because their fillings contracted and fell out. Finally Dr. Siple invented a non-contracting mixture.

Principles of Clothing and Food

The chief principle of clothing is to retain the natural heat of the body and not to let it escape. In a completely insulated house we should need no fires at all. Our own body heat would suffice to keep us warm. Air is a bad conductor of heat, and wool and furs are useful as heat preservers because they keep still air entangled. Human beings can moreover create a zone of stagnant air around their bodies by surrounding it with at least two layers of clothing. In countries where the people know that it is cold in winter, all houses, following the same principle, have two sets of window-panes. Similarly, polar travellers build their tents out of two thin layers of fabric separated by six inches of air.

Woollen garments are good enough as long as the air is still, but they do not protect against wind. For this

purpose, long staple cotton fabric of dense weave is recommended as ideal as it is almost impervious to wind and still allows the vapour of perspiration to pass out. Sleeping bags are made of eiderdown which is an even poorer conductor of heat than air.

Clothing must be kept absolutely dry. Damp cloth conducts heat and, besides, every particle of water or sweat turns immediately to ice. It is hair-raising to read what polar travellers hardly 30 years ago suffered from their sleeping bags clogged with ice, garments stiff like sheets of armour plate, frozen boots into which to squeeze one's feet was an hour's ordeal. The explorer of to-day leads a comparatively comfortable life, even without luxurious huts, in his double-walled tent which stands firm against wind, with the high pressure Primus stove drying all the clothing overnight and with restful sleep provided by the bulky eiderdown, where mouth and nose lie at the bottom of a deep fold, so that the breath has a long way to go before it freezes outside the bag.

As regards *Feeding*, the chief problems are not set at the base where there may be ample supplies, but on sledging parties where every ounce counts, and the ration must be computed in such a way that the intake of energy just balances the output. A measure for the efficiency of the party is the number of calories carried along per pound of total sledge load. The hauling capacity of a nine-dog team is 900 pounds. Food for 2 men and 9 dogs amounts to 550 pounds for a month, fuel and camping equipment to 350 pounds. So thirty days' travel are safe—if nothing happens.

A comparison between the daily rations of 1875 with the present ones, as given by Dr. Bertram, is interesting.

1875	*Now*
16 oz. Pemmican	7 oz. Pemmican
4 oz. Bacon	6 oz. Margarine
14 oz. Biscuits	3 oz. Biscuits
2 oz. Potatoes	2 oz. Pea Flour
2½ oz. Sugar	3 oz. Sugar

the East Base is only 68° W and the West Base 164° W. Arithmetically it is indisputable that 164 is "more west" than 68. On this counting the western direction goes to the left as far as 90 degrees, then turns round and goes on to to the right.

However, the West Base with its 164° is only 16 degrees distant from the eastern hemisphere, i.e. 52 degrees nearer to the east or "more east" than the so-called East Base.

Further, in dealing with the pole we must keep in mind the different character of meridians and parallels. Meridians are the lines which connect the north pole with the south pole. They are all great circles and all equal. One degree of latitude, that is the 360th part of their circumference, has everywhere the same length. Not so the parallels. They shrink from the equator to the pole, and while one degree of longitude covers 69 miles on the equator, it covers only 12 miles at a latitude of 80 degrees. That is why polar travellers can manipulate longitude differences which may seem to us fantastic.

Polar explorers have often made much greater mistakes in ascertaining their longitude than their latitude. The unreliability of chronometers at very low temperatures is said to account for this weakness. Cannot the extreme smallness of the degrees also have something to do with it?

3. SCIENTIFIC RESULTS

Antarctica versus Arctica

Geography teaches that the polar zones are separated from the temperate zones by the Polar Circles in latitude 66° 33′ north and south, these being the lines beyond which during the summer the sun never disappears. There is a fundamental contrast between the North Pole and the South Pole. Not as a certain professor of philosophy imagined when he addressed his students with rhetorical pathos: "Whether you are shivering in the biting frost of

the ice-bound north pole, or suffocating in the torrid heat of the south pole . . .". No, not that. But there *is* a contrast between the two poles.

From the equator upwards to the north the continental mass broadens and has its greatest extension in medium latitudes, then the land recedes. The north pole is surrounded by water and is at sea level. From the equator downwards to the south, the land masses get narrower everywhere, but while between 35° and 65° S water prevails, we find beyond this latitude the vast Antarctic Continent with its six million square miles, bigger than the United States, bigger than Europe or Australia. The South Pole is embedded in this continent, lying on a plateau almost 10,000 feet in height.

The Arctic has a comparatively warm summer and as the lands around the polar sea are continuous with those of the temperate zone, they contain a rich flora and fauna including such land animals as the reindeer, the polar bear and the musk ox. In the Antarctic the temperature even in summer rises seldom above freezing (=melting) point. If the traveller exceptionally sees a green carpet, it consists of mosses and lichens. The even rarer occasions when he hits on a few specimens of a flowering plant assume almost festive character. The biggest land animal compares poorly with the musk ox, as its length is five millimetres. It is a wingless gnat.

The Antarctic waters, however, are in contact with the temperate zone and the sea animals can go north whenever it suits them. The waters teem with life, from microscopic crustaceans and rotifers up to whales of 100 feet length. Whereas in other continents, the continental shelf is only about 100 fathoms deep, the Antarctic mountains fall down to 1,000 fathoms. Warm waters emerge from the depth rich in mineral salts all around the continent. This together with the long daylight produces a rich concentration of plankton. For the temperate zone the close contact with the polar regions is not altogether pleasant

as pack ice and ice-bergs, (of which one was 300 miles in length) penetrate far into the north, and cold bottom currents reach in some places as far as the equator.

At the surface the antarctic and sub-antarctic waters meet along a sharp boundary called the "Antarctic Convergence" which was discovered by Meinardus in 1923 and extensively studied since by the Discovery Committee. Its position is nearly half-way between the antarctic and the other continents, roughly at 60° S, just outside the pack ice limit. It seems to go all round the continent, but has a tortuous contour including twists and loops.

The Convergence, not the Polar Circle, is biologically considered the boundary of Antarctica. Here the temperature of the surface water (down to 600 feet) changes abruptly, and certain species of micro-organisms and even of fishes cannot cross this barrier.

Geography and Geology

The polar plateau appears as an ice cap of unknown thickness which descends outwards to the coasts. Still there is enough bare rock to satisfy the geologist. The solid mass of these mountains is igneous, partly volcanic, and one volcano, Mt. Erebus on Ross Island, sends up to the sky a high cloud plume which serves as a weather vane.

Between the rocks of Graham Land and the South American Andes there is a striking similarity and an ancient land bridge is assumed between the two continents. Echo soundings have revealed extensive submarine connections between S. America and Antarctica. According to the Byrdian, Mr. Bryant, what little flora exists is evidence for land bridges, connecting Antarctica not only with South America but also with New Zealand.

The geographical discoveries of the Grahamers contain one chapter which is pathetic. In Griffith Taylor's instructive book *Antarctic Adventure and Research* (1930) we read that "December 20th, 1928, was the most wonderful day, ... Sir Hubert Wilkins settled more problems

and sketched more new coast-lines than any other expedition had accomplished."

His chief glory was the discovery of several straits running west and east across Graham Land, separating it from the continent. The main strait or sound which Wilkins called Stefansson Strait would have provided a splendid avenue to the south of the Weddell Sea which otherwise was almost inaccessible from the west. So Mr. Rymill's party based their plans on making use of Stefansson Strait. But what Wilkins looking down from the air had regarded as a strait was really a very high glacier valley not reachable from the coast. It cost one of the Grahamers, Mr. A. Stephensen, after his return to England a vast amount of labour to prove with overwhelming evidence that there is no Stefansson Strait and that Graham Land is indeed part of the main land as it was believed to be—until that wonderful day in December.

From this the lesson was drawn that a flier, especially over ice- or snow-covered country, is unable to determine heights, and air reconnaissance without the help of some known ground features is insufficient. Indeed, a very important real strait over 200 miles long and 15–20 miles wide which the Grahamers discovered was not sighted at all by Mr. Lincoln Ellsworth when he flew over the country.

This new strait called *King George VI Sound* is the major discovery of Rymill's party. On the shelf ice of this sound one can sledge without great difficulty, and it may open a route to the heart of the continent and to still unknown coastal areas to the west. Unfortunately the Grahamers, having wasted so much time on the Stefansson Strait, could not pursue their discovery to the end. They followed the sound down a long way until it turned west, but had to leave off without knowing how far west it went and whether it ended in high land or in the sea. The map shows the sound at this stage of uncertainty. The Byrdians who had carefully studied Mr. Rymill's book carried on his work and established that the sound opens to the west to a great

ice-free sea. Thus Alexander I Land, so named by the Rüssian Bellingshausen who discovered it in 1820, has now become Alexander I Island.

The channel is also of geological importance as it separates provinces of very different character. East of King George Sound is Graham Land with its bedrock, west of it runs the 8,000-foot mountain range of Alexander I Island which contains sediments carrying a rich assortment of fossils.

It would seem as if here and there, scattered over the continent, almost all types of fossils are represented—except reptiles and mammals. Some fossil plants indicate an ancient subtropical climate.

As to minerals, only low-grade coal has been found and isolated deposits of copper ores. Nor is there any definite evidence for oil-bearing layers.

The Weddell Sea and the Ross Sea

These two large bays are the only ones which cut deep into the otherwise massive bulk of the Antarctic Continent. The Weddell Sea is in the British, the Ross Sea in the New Zealand sector. They are both inhabited by that uncanny white monster, the Pack, which guards the coasts of the continent. If ships try to defy the monster, they soon feel gripped in its icy claws, kept prisoner indefinitely, kicked about, and not too rarely crushed to pieces—as happened to Shackleton's "Endurance" and to Nordenskjold's "Antarctic".

The Weddell Sea is of particular interest to oceanographers as the source of the antarctic bottom current. For some reason the cold shelf water in this bay—but nowhere else—sinks to the ocean bed and from there spreads, not only through the whole Southern Ocean but even northwards into all the other three (Atlantic, Pacific, Indian).

Now there is something almost magical in this Weddell S[illegible] for the territories of S. Georgia, the S. Orkney

and Sandwich Islands are, under its influence, extremely rich in animals and plants compared with the territory west of them. "One would like to know", says an expert, "the history of the water which leaves the Weddell Sea, i.e., the water which enters it from the east." We shall see in the Biology paragraphs that the neighbourhood of the Weddell Sea seems favourable for reproduction.

The polar end of both bays is filled with *shelf ice*, a fascinating, awe-inspiring, tremendous mystery, a structure which has aroused more interest than any other glacial type. No colossal sheet of that kind is known in the north.

The Filchner Ice Shelf at the head of the Weddell Sea is completely unexplored, but the Ross Ice Shelf has been frequently surveyed. The Byrdians had their West Base right on the shelf ice and constructed a special Ice Laboratory on it. It is interesting that their leading scientist, Professor Alton Wade, consulted the British Glaciological Society about the experimental programme.

The Ross Shelf is a triangle whose seaward face runs nearly west and east and is about 400–500 miles long. As the shelf is in slow but constant movement, the measurements change. Its total area is roughly the size of France. Where the shelf bars the way, sailors called it a Barrier.

The characteristic of a shelf is that its seaward end floats freely on the water. When a ship is moored to the ice, it moves up and down with the tide in unison with the ice shelf. But the inner end is held fast to the continent by the glaciers which act as feeders, and by being aground close to the coast. Near the margin or where glaciers enter it, the sheet may be thrown into pressure waves some forty feet high and 1–2 miles from crest to crest. On aerial photographs the ice may then appear like jelly or junket. Otherwise the Ross Shelf surface is smooth, and as it reaches within 300 miles of the South Pole, it has always been chosen as the avenue to that spot.

A problem child of the Ross Sea is the *Bay of Whales*

Wade and Siple have now decided that the Bay is a meeting place of two shelf ice systems, one hailing from the south, the other from the south-east. As they encounter the native bay ice, they crumple, and the patterns they form are so similar to the fractures in the crust of the earth that the American Geological Society has provided a grant for a detailed map of this intricate deformation pattern. As the crust of the earth is also regarded as a thin layer floating on a plastic medium, the study of ice in the Antarctic might offer a solution for European or American mountain problems.

Antarctic Ice

It is generally assumed that the ice cover of the Antarctic lands was mightier in earlier times and is now receding. Mr. Fleming called attention to some striking configurations which could only have originated in a climate colder than ours, when the snow limit was at sea level.

On the West coast of Graham Land, mountains rise from the sea to heights of 6,000–8,000 feet. Between them and the shore there is a belt of "fringing glaciers", which end seawards in ice cliffs up to more than 100 feet in height which rest on rock at sea level. Had they originated recently, their length should be in proportion to this height. But it is not. They are quite short. Similarly tiny islands wear ice caps much too thick for their width. Both these ice caps and those glaciers must have formed part of an enormous ice shelf of the Ross Shelf type. Mr. Fleming thinks the sheet has broken away quite recently and the fringing glaciers may disappear within a few years.

As Professor Wade established, there is a fundamental difference between the structure of ice in places where it melts periodically and in the Shelf where it never melts. In Spitsbergen or in the Alps one can see boundary lines between two years' accumulations, because a crust is formed when the surface melts in the presence of fine dust [illegible] In the Ross Shelf there is no melting and no

dust, and therefore no crust. Perhaps the lack of dust is the most essential, for dust acts as a "black body" which absorbs all the available radiation and by the heat thus concentrated melts the ice around.

A local heat effect of that kind is indeed noted in central Antarctica where dark mountains and their debris act as radiators and produce, temporarily, a lake district in a country which normally is a waterless desert.

The lack of melting seems also to prevent the orientation of ice crystals as found by *Seligmann* and *Perutz* in the Jungfraujoch Glacier. In order to arrange themselves according to plan, crystals apparently must melt and re-crystallise*.

The density of the shelf ice increases greatly with the depth. The upper layers can be easily cut with a saw, but below five metre depth the ice must be blasted. The hardness of ice also increases remarkably as the temperature decreases. At —100° F. ice is as hard as orthoclase felspar. This explains why being hit by ice crystals during a blizzard can hurt so much and why sledge runners suffer excessively from low temperatures.

In the Ross Shelf the winter cold wave was found to penetrate to about five metre depth. At fifteen metres there were no changes at all, the temperature remaining constant at about the yearly average of —23.7°C. (—10° F.). Lower down it seemed that it even increased owing to warmer sea water currents.

Biology

Physiologically the Antarctic is a desert, the air is extremely dry and the surface frozen. But wherever temporarily, through thawing, a pool or a trickle of water is formed, there is immediately rich life in it. Small ponds appear choked with gelatinous algae and microscopic animals such as rotifers or crustaceans. Of two pools side by side, one may contain only adult crustaceans, the other only young ones.

* But see pp. 114 et seq.

On the Argentine Islands (65°S.) and also on an island further south, Dr. Bertram found a very rich botanical display, consisting of a most remarkable sporadic occurrence of a closed moss association up to an acre in area. In places the moss formed a peat three feet thick, but except for a few inches at the surface which thawed up in summer it was permanently frozen.

In these places, one of the two flowering plants which the Antarctic can boast was also present. It is a relative of pinks and campions, called *Colobanthus crassifolius*. The other flowering plant is *Deschampsia antarctica*, a grass often seen scattered in small tufts. No flowering plants have yet been found anywhere on the continent outside Graham Land. The typical antarctic plants are the lichens. Three of their species occur also in South America and 25 in New Zealand.

Various tiny terrestrial insects live south of the Antarctic Circle. One Collembola species was found floating in a trickle of water below a snow bank and it seemed to emerge from an algae-covered crack in the rocks. Wherever there was a small water course, Collembola could be collected from it in swarms so thick that they looked like blotches of soot. When over night the water froze, Collembola was to be seen nowhere. Mites are much more frequent than insects.

Near the penguin rookeries rich vegetation develops,but one observer rejects the obvious inference that the bird manure is responsible for this.

Birds there are in plenty, gulls and terns and skuas, and the water contains a great variety of animals.

In the following paragraphs I give only a few data about those animals which have been specially studied recently, viz. seals, petrels and penguins.

Seals

The antarctic animals are not yet afraid of man. Birds as well as seals can be freely watched and easily killed.

Seals lie placidly on the beach awaiting the enemy and keep their serenity even when a few of their fellows have been put to death before their eyes.

Most antarctic seals are "True Seals" as distinguished from Eared Seals and Walruses. The most powerful among them is the Sea Elephant which is now kept under Government control in S. Georgia after an immense and wasteful slaughter had almost exterminated the species. The male sea elephant is bigger than his female and is polygamous. An interesting correlation has been noted between sex sizes and polygamy. Thus the northern Fur Seal which may be six times as big as the female, commands a harem of 40 to 70 cows fighting off all rivals. But in most antarctic seals the female is slightly bigger. The Sea Leopard, 12 ft. long, of snake-like appearance, does not live gregariously like the others and is a vicious predator. It eats little seals and penguins.

The Ross Seal, 7 ft. long, is very rare. Only a few were sighted in the Ross Sea.

The most common seals in West Antarctica are the Weddell Seal, 10 ft. long, and the Crabeater (8 ft.). Dr. Bertram, a Grahamer, in order to study them thoroughly, took upon himself the gruesome work of butchering almost all the 367 Weddell Seals and 177 Crabeaters which were required to feed men and dogs.

The Weddell Seals live mostly in the water and in winter below the ice. They use their sharp teeth to saw out breathing holes or enlarge existing cracks. But this hard job soon wears their teeth out, and when they lose their teeth, they must perish. These poor seals are very unhealthy creatures. They have nasty skin diseases, large festering sores, their wounds heal very slowly, their bowels are choked with worms of all kinds. Nor do they live long, not more than eight years probably.

Their age can, as with whales, be estimated from the number of "yellow bodies" in their ovaries. These are the follicles from which eggs are formed and which in the

Weddell Seal persist unto death. As a seal develops only one egg a year, the number of yellow bodies in the females gives an indication as to their age.

Copulation has never been seen and obviously occurs in the water. In spring (September) the cows come out on the beaches and give birth to one pup each.

The pregnancy lasts very long, ten months, and when the pup appears, it is almost ready for an independent life. It weighs 60 lb. and gains 7 each day by suckling. It is born with a thick woolly coat which it soon exchanges for the hair of the adult. Then it goes into the water and is rarely seen again until it is sexually mature.

This stage is reached in the Antarctic a year earlier than in the north. Weddell Seals become pregnant at 26 months, Crabeaters even at 15 months.

Weddell Seals live on fish and cephalopods, Crabeaters on a shrimp-like Crustacean known as Krill which is present in such immense quantities as to satisfy even the appetite of giant whales.

Crabeaters do not show traces in their teeth of sawing, though they too live below the ice. They have no diseases, no worms, and while there is hardly one which does not carry on its body enormous parallel scars inflicted by the teeth of the Killer Whale, even this does not seem to disturb their health.

Antarctic seals can sing. They command a whole octave of musical notes and it takes authors many lines to describe the variety of their utterances.

When a seal is wounded or otherwise senses its approaching death, it retires as far as thirty miles into the interior or on a mountain 2,000 feet high, there to die in solitude and dignity.

Petrels and Penguins

When we hear that birds leave our inhospitable north in the autumn to spend their winter in the south, the last place where we should expect them to go is the neighbour-

hood of the south pole. Yet Wilson's Petrel, a bird which is seen in the Persian Gulf, in Peru and in the Red Sea, has got it into his head that he cannot breed anywhere else than in Antarctica. Dr. Brian Roberts, of the Grahamers, was fortunate enough to have a nesting colony of these birds in a small moss patch on the Argentine Islands and could watch their courtship and breeding habits—their flying around the island every evening for a week without going ashore, their flitting up and down and around the colony, occasionally alighting, for another week, until at last they settled down. As was revealed by the rings attached to their feet, each bird moved into his "old digs" together with his old mate. Dr. Roberts thinks it is the common accommodation which keeps the couples together, rather than love. One can find several subsequent residences, one on top of the other, as in some excavated Oriental cities. When the egg is laid, only one every year, each parent sits on it for 48 hours in rigid rhythm, and if a scientist kidnaps a sitting bird, the egg is left alone until the time appointed for the changeover. It does not seem to hurt the egg. In April, at the end of the southern summer, the petrels go north where they successfully escape scientific observation.

Petrels live in general on Krill, but they are also fond of oil and assemble in huge flocks round floating whale factories, feeding on scattered oil drops. Their habit of ejecting oil has been shrewdly utilised in some places: if a wick is drawn through their mouth and anus, it serves as a candle.

Neither in petrels nor in penguins is there any sex distinction during the courtship, and the aim of all display is, according to Dr. Roberts, definitely not to woo and select a mate. The breeding cycle of all higher organisms, including such activities as nest building, is regulated by hormones and the glands which supply them. But the glands in their turn respond to stimuli and these include season and climate as well as the appearance and behaviour of the other partner. "The pair which has the greatest

capacity for mutual stimulation will be the most successful in perpetuating the race."

Birds themselves cannot distinguish sex visually. They can only find out by trial and error. They call and see what response they get. That is apparently why they call so much. In penguins large-scale ringing had not yet been performed, so Roberts could do nothing but watch the birds' behaviour first and then ascertain their sex by a post-mortem. Before copulation both sexes behave as males. It looks as if the female characters were developed later only.

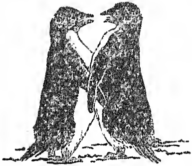

Fig. 2.—Fighting.

The breeding period is introduced by much crowing. The penguins sort themselves out in pairs and these call

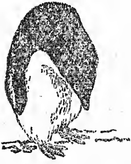

Fig. 3.—Bowing.

and bow to each other. They are strongly addicted to ceremonious bowing, and the high-light of the photos taken is the picture of a bird who, with a deep and respectful bow, lays a pebble at the feet of his beloved. Pebbles are not just jewellery, they are used for nest building, and also swallowed by penguins as well as seals. Whether they help to grind the food is not yet clear.

Fig. 4.—Copulation.

In the pre-laying period penguins often assume an "ecstatic attitude", neck elongated, bill raised to heaven, flippers beating in a slow rhythm, accompanied by braying or trumpeting. If one bird starts the display, all the others soon join in.

Penguins have a passion for brooding out something, preferably an egg, but a lump of dirty ice may also do. Hatching is done in turns, and there is a special "nest relief ceremony", for if the relief approaches the nest without hissing the pass word and bowing elaborately, it is attacked.

Fig. 5.—Nest-relief ceremony.

Sometimes penguins will strike attitudes, pick up and deposit pebbles when they are alone, or prepare a nest and leave it unoccupied. Such apparently aimless behaviour seems one more illustration of the theory that most games of young animals are a preparation for the earnest of life.

While the parents go out to get food, all the young of a rookery are assembled in crêches with a pair of adults to keep them together. These nurses, however, did not budge when an enemy attacked and disembowelled some of the chicks.

In general, penguins lay their eggs in spring or summer, only the Emperor Penguins lay theirs in midwinter, and it is a heroic story worth recounting that the worst part of "The Worst Journey in the World"—five weeks in utter darkness at a temperature between 60 and 77 degrees below zero in a blizzard which blew the tent away—was undertaken by three martyrs of science, Wilson, Bowers and Cherry-Garrard, for no other purpose than to secure some of these eggs. Why? Because the Emperor Penguin is the most primitive of all penguins, and the idea was, in accordance with the evolutionary notions prevailing at that time, to find in the embyro "the missing link between birds and reptiles". Unfortunately, none of the eggs they brought back to England contained an embryo.

Austere and dangerous as the explorer's life may be, it has its peculiar reward—not only the satisfaction of the sportsman and of the scientist, but deeper spiritual joy. Shackleton wrote: "When I look back at those days, I have no doubt that Providence guided us. I know that during that long and racking march it seemed to me often that we were four, not three. I said nothing to my companions, but afterwards Wordsley said to me: 'Boss, I had a curious feeling on the march that there was another person with us.' Crean confessed to the same idea. A record of our journeys would be incomplete without reference to a subject which is very near our hearts."

Colin Bertram quoting these words adds that to most

travellers in the empty places of the earth is given something of the feelings of mystics and hermits and a re-adjustment of relative values, and that they may find a deeper and wider meaning in the Scott epitaph on the Polar Research Institute:

QUAESIVIT ARCANA POLI VIDET DEI

It might to them mean: He who has searched for the mysteries of the pole, sees the mystery of God.

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Making Penicillin

BY DR. E. LESTER SMITH AND J. L. CRAMMER

THERE are three historic occasions in the story of Penicillin. The first was its discovery by Fleming in 1929; the second, 1932, a report on its chemical properties by Raistrick; and the third and most exciting, the announcement of its great medical importance by Florey in 1940. His Oxford group of scientists had found out how to make the drug sufficiently pure to treat human sickness, though the quantities available were enough only for one or two cases.

The publicised story usually stops at this point as though the whole work were then done. In fact, however, it was only the beginning of a vast cooperative effort to find out how to make the drug on a factory scale. Its production in the laboratory by skilled chemists working at their own speed with straggling glass apparatus could be little guide to mass production by unskilled labour. In the factory we are faced with the effort to make the maximum quantity of pure penicillin in the minimum possible time, we have to think of the cost, of the space required to make it in, of fool-proofing the processes, of guiding and checking them, and of employing the available factories and labour as efficiently as possible by making the purification production process continuous. This involved much research in botany, chemistry, chemical engineering, and bacteriology, as we shall shortly see. There was an added complication, which affected the whole development of the processes: Britain was at war, and materials and labour were in short supply.

The essence of making penicillin is simple. A mould, *Penicillium notatum*, is grown on a watery solution containing various salts and sugar. As it grows it forms small amounts of penicillin which it excretes into the water.

Eventually, the mould is skimmed or filtered off and thrown away, and the penicillin extracted from the fluid on which it formerly grew. There are several ways of extraction and the most important depends on the fact that penicillin is an acid substance which can be pushed about from water into chloroform (for instance) and back again by altering the acidity or alkalinity of the water layer. For it must be remembered that there are a very large number of liquids which do not mix appreciably with water, but float on its surface like oil, or rest heavily beneath it, when the two are placed together in a tank.

Such, for instance, are ether, chloroform, amyl alcohol and acetate, which will all dissolve penicillin quite readily, provided it is present as an acid, and not as a salt. So the culture medium is made acid and shaken with amyl acetate and the penicillin passes into the amyl acetate layer, leaving the salts and many impurities behind.

The amyl acetate is then separated off, and shaken with clean water, which has been made a little alkaline. Now the penicillin passes back into the water again. The water is drawn off, made acid, and shaken with chloroform which now picks up the penicillin in its turn, to yield it again to fresh alkaline water, for instance containing lime, so that the calcium salt of penicillin is prepared ready for use.

This all sounds simple enough to anyone who knows a little chemistry. It is basically how the Oxford workers made the first specimens of penicillin. Where are the snags? Let us go back and view the process in more detail, and they will quickly emerge.

The Horticultural Problem

Penicillium is a living plant, and the first step is to grow it. In ordinary gardening the aim is to get the biggest marrows, the juiciest and reddest tomatoes; in this special form of horticulture, however, the goal is quite different. We do not care for the plant at all: we are after a particular substance rather easily damaged, which the plant happens

apparently accidentally to excrete into the soil in small quantities. Penicillin is not the only, or even the chief substance, that it excretes. In the early experiments, the medium at the best contained about 10 units penicillin per ml. (equivalent to six millionths of a gramme of pure sodium penicillin II), and a single patient requires 100,000 units every three or four hours, often for several days. The first big research problem was thus how to make the plant produce the maximum of penicillin, and it was soon found best to grow it at 24°C, for about seven to eleven days before harvesting: for the penicillin produced increases slowly as the plant grows, and then after a time is slowly destroyed again by further growth, so that the maturing cultures must be carefully watched. As the plant grows it consumes a great deal of oxygen and exhales much carbon dioxide, so that gases must be allowed free entry and exit to the plant. As it grows, too, it produces warmth, like the heat of fermenting grass in a manure pile, so the circulating air must distribute this heat, or carry it away, if the temperature is to be kept at the desirable 24°C.

When this was settled the question of the best "soil" and the best "manure" became important. At the start every one used a synthetic medium—a mixture of phosphates, sulphates, chlorides and nitrates of sodium, potassium, magnesium, and iron together with 4 per cent of sugar (glucose) all dissolved in water. This Czapek-Dox medium, as it is called, is a stock one in the laboratory for growing moulds of all kinds for research purposes, and is similar to the solutions for water culture of green plants, as in hydroponics. It did not always give very good results, and it was found that the mould needed also traces of copper and zinc, not supplied in the Czapek-Dox mixture, but obtained haphazard from the glass of the growth tank, or from impurities in the water. Many experiments were tried with different foods for the mould, until finally the Americans hit on a really good medium, which was not synthetic but conveniently the by-product from another

industry. In the manufacture of starch, maize is steeped in warm water; various substances are soaked out and undergo a certain amount of bacterial fermentation. Originally this corn steep liquor had to be thrown away. After the addition of lactose (milk sugar), however, it was found to be ideal for growing *Penicillium notatum*, and using it one can get over 200 units of penicillin per ml., a twentyfold improvement on the starting position. What makes corn steep liquor so good seems to be a whole mixture of substances present, and so it is better to use the natural brown syrupy liquor than try for a synthetic substitute.

One further bright idea came out when the chemical structure of penicillin was finally solved. It was thought that it might be possible to provide some of the actual materials which the mould uses in building up the drug molecule, and so save it the labour of making these building bricks first, as it grew, and thus speed up production. Chemicals were found which would actually do this, but they are still on the secret list.

Another aspect of the botanical problem altogether was the question of the best "seed". Just as there are many different varieties of potatoes and roses, so there are many strains of *penicillium notatum*, which vary in their penicillin-producing power. A wide search was conducted through all the known laboratory-civilised strains, fresh wild strains were isolated from soils in various places, and a new line of research sprang up and is still very actively under way. When a mould gets a dose of X-rays, or ultra-violet light, or treatment with certain special chemicals, such as mustard gas, its chromosomes are affected, and consequently its inheritance altered so that its "seeds" or spores will grow into young moulds differing in a haphazard variety of ways from their parents. These mutations, as they are called, are then studied one by one for biological differences, such as better penicillin production, speedier growth, and so on, in the hopes that one day the perfect mould will

turn up, which will spend its whole time and energy penicillin making.

What about "weeds"? These turn out to be particularly menacing in the *Penicillium* garden. Many bacteria produce an enzyme or digestive ferment called penicillinase which smashes penicillin up in no time. Therefore all the culture fluids have to be carefully sterilised, all the culture vessels likewise, the seeds have to be sown aseptically, the air must be bacteria-free—in all the early stages a sharp look-out must be kept for "weeds". In the early days, when the mould was grown in hundreds and thousands of milk bottles,* and the contents later pooled, pencillinase from one weedy bottle might ruin the whole lot, and the weeds might be invisible at that. It was very necessary to train and supervise the ordinary unskilled labour available in the proper aseptic techniques for plugging the sterile bottles with sterile cotton wool and so on, to avoid this very unwelcome penicillinase production. Each sterile milk bottle had later to be momentarily unplugged and inoculated with penicillium spores, and here again was a dangerous manoeuvre. The spores were usually suspended in a little sterile water and sprayed or shot in from a pipette delivering constant volumes, and this required specially trained operators.

The production of the spores from the chosen strain of mould in itself is an important job needing a special department of the factory. The strain has to be kept pure, free from foreign moulds and bacteria, and unchanging in its growth and habits. With continued subculture there is always the danger that a natural mutation may occur, or the mould drift into another way of living, just as disease bacteria grown for generations on laboratory media lose their virulence and become mild.

* Milk bottles were chosen in wartime as being easily available; and the big dairies had already worked out how to handle them in bulk on a moving belt for washing, sterilising, filling, etc. One pharmaceutical company alone acquired three quarters of a million of them.

The Engineering Problem

While botanical research, or more precisely, microbiological experiments, defined the sort of conditions required, the engineers were busy supplying those conditions on a mass scale. Since the mould would only grow on the surface of the culture medium, where there was plenty of air, it was necessary to get a large fluid surface, and at first this was obtained by putting the medium in thousands of milk bottles lying on their sides, 10° from the full horizontal so that the cotton-wool plugs were not wetted. Amongst several drawbacks one important one was the varying depth of liquid in such a bottle, leading to non-uniform growth, and waste.

Glaxo therefore designed and used special glass vessels shaped rather like sealed saucepans with an entrance through a hollow handle (Plate 13). These could be easily stacked and handled and contained a uniform depth of culture fluid. Test showed that the "handle" entrance was big enough for free circulation of gases; but the shape was very awkward for washing, and the vessels expensive to make.

There were other approaches to the growth problem. Some firms tried growing the mould in shallow trays. Although apparently simple, this too had snags: the trays had to be fairly small, rigid, and carefully levelled; each filled with the right amount of medium, aseptically inoculated with spores, and incubated for a week or so in a current of sterile air. It was possible to arrange the trays in banks, so that sterile medium flowed in at the top and slowly overflowed from one tray to the next, emerging rich in penicillin at the bottom—but in practice this was difficult. Another method was to grow the mould on moist bran. A third was modelled on vinegar manufacture. Sterile medium flows slowly down towers packed with some inert sterile support inoculated with mould spores. After a time the outflowing liquid contains penicillin, and output is continuous until the tower chokes with mould, or gets infected by penicillinase-making bacteria.

From the beginning there was always the dream that the mould might be persuaded to grow submerged and scattered throughout a large tank of medium, but early trials were very discouraging. It seemed the mould would only grow on the surface. However, the Americans persevered, and after spending millions of dollars were able finally to announce success. In fact the deep tank submerged culture method of penicillin manufacture has now become the standard method in industrial production in both the United States and Britain. Tanks containing 5,000—10,000 gallons are commonly used and growth takes only a few days: one tank of this sort produces penicillin at the same rate as half a million milk bottles (Plate 15).

The basic engineering problem which was so difficult to solve, was how to keep a tankful of medium, through which plenty of sterile air had to be blown and the liquid well stirred, completely free of bacterial contamination for several days. Its solution demanded the invention of many ingenious devices which are closely guarded industrial secrets. There were also subsidiary problems. One was what to make the tanks out of. Early research suggested that even traces of most metals would rapidly destroy penicillin, but fortunately stainless steel was found to be harmless and therefore very suitable. The change from surface to deep culture meant that other strains of *penicillium notatum* would now grow better, and changes in the chemical composition of the culture medium became necessary. This in turn rebounded on the rest of the factory, which also had to be modified. As just one example of how improvement in one part of a process upsets the rest, requiring yet more research and development to set it right, we may mention that in the early days the first treatment of the culture medium after growth was with charcoal, which adsorbed the penicillin from solution: later the penicillin could be got back into a small amount of clean liquid, thus purified and concentrated. When however, corn steep liquor came into use as culture medium,

the charcoal process would no longer work advantageously, and had to be abandoned.

Today, after the growth of mould has been filtered off (see Plate 16), the fluid is acidified and extracted with amyl acetate: the two solvents are well mixed together and then quickly separated again in a centrifuge which spins them apart (see Plate 17). The centrifuge, incidentally, is an instrument already important industrially in oil refining for separating oil from water with which it has been washed, so that this part of the penicillin process has required adaptation rather than invention. The concentration and purification of penicillin then proceeds on the lines already briefly sketched, passing it back and forth between pairs of solvents. The secrets of the process lie in the accurate adjustment of the precise acidity or alkalinity of the water each time. This is vital for two reasons. One is that penicillin is unstable and begins to decompose if its solution gets far from neutrality on either acid or alkaline side, so that a process involving such changes is risky and needs very careful control. The other reason is that the degree of purity achieved depends on it. When penicillin passes from water into amyl acetate, so to a certain extent do some other substances present in the culture medium, either unused components of the corn steep liquor, or other products excreted by the mould. The precise degree to which these impurities pass over from solvent to solvent each time also depends on the acidity, though the best conditions are not identical with the best conditions for penicillin stability. Therefore, by very careful adjustment, it is possible each time to leave a very large proportion of the impurities behind, and so to get purer and purer penicillin, though a small proportion of the penicillin has to be sacrificed at each stage.

This will yield penicillin from about 30 per cent to 80 per cent pure, which is good enough for ordinary medical purposes. 100 per cent pure white crystalline penicillin is also available for special cases such as brain surgery, but

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it is much more expensive, because the extra refining, involving recrystallisation of penicillin as the salt of an organic base, is a skilled business (Plate 21).

Penicillin keeps best in the dry state, and the final stage in its processing is to dry it (see Plates 19 and 20). It was found best to put the right amount of 10 per cent solution into each vial or ampoule and then dry it by freezing the solution quickly with solid carbon dioxide to —30°C and applying a high vacuum to "suck off" the frozen water. This process of freeze-drying is very suitable for unstable substances like penicillin. It has been much used also in preparing dried blood plasma (another fragile stuff), stored thus for transfusions. The secret of success is to have exactly the right conditions—and finding them was a great deal of work. A really good vacuum (about 0.02 mm. mercury) is essential, and so is a good condenser (at about —50°C) to trap and solidify the ice-vapour in another part of the system. When completely dry, the ampoules are sealed off, labelled, packed: the drug is ready for use.

Laboratory Studies

Naturally a great deal of work has been done to find out what destroys penicillin and what preserves it. Some of the destructive agencies—penicillinase, metal ions, acidity, heat, have already been mentioned. A sharp look out must be kept for them during manufacture, and in addition the amount of penicillin present in the culture fluid at harvesting of the mould, and the amount present in solution at the end of processing before drying, must be assayed as a matter of routine. From such a practice we learn that under present conditions about 40 cent of the penicillin is lost during manufacture; nevertheless, this is commercially good enough. The solution is filtered through a Seitz filter before drying to remove bacteria. Batches of the dried product are also tested in the bacteriological laboratory to make sure they are in fact free of

germs.* Some of the batch is injected into rabbits to make sure it is free of the mysterious impurities which will cause sudden rises of temperature and rigors when injected. A further sample is injected into mice to be certain that it is non-poisonous.

Clearly all these tests require trained scientific workers. Clearly also, the running of such an industry, and the solution of the multifarious problems that arise needs chemical engineers, biologists, chemists. The production of streptomycin, the only other antibiotic of industrial interest at present, is much less developed, and offers many similar problems to be tackled. It is partly out of the recognition of the growing importance of the whole field that the University of Cambridge has this year for the first time instituted a special advanced twelve months' course in chemical microbiology.

The growing importance of the penicillin industry itself is shown by the following figures. They give the average monthly output in millions of units:

	U.S.A.	*Britain*
1943	1,700	300
1944	138,000	3,200
1945	570,000	26,000
1946	800,000	260,000
1947	1,000,000	400,000

They are a measure of the success achieved in the largest (non-military) scientific combined operation hitherto undertaken by mankind, and a stimulus and guide to future effort.

* To make such a test, the penicillin in the sample is first destroyed with penicillinase, and then the sample placed on the usual broths, blood agar medium, etc., on which any bacterial growth can occur. Any germ present will thus reveal itself.

Farming Front

BY R. N. HIGINBOTHAM

The N.A.A.S.

AT the beginning of July last, the farming community had the pleasure of reading about or attending the first Royal Show since before the war, and the differences between Windsor (1939) and Lincoln (1947) were much remarked upon. In particular, exhibits designed by the various advisory services available to agriculture were on a larger scale than ever before. The main organisation concerned in this was the newly-founded National Agricultural Advisory Service, which is now the chief instrument of scientific popularisation for the industry. Such organisations as the Milk Marketing Board and the Department of Scientific and Industrial Research, which, together with commercial firms and producers' societies, provide a great deal of useful information, were also represented. But there is a difference between them and the N.A.A.S., which is the only body giving advice on the whole of agriculture to all producers in all parts of the country. As such it has been specifically designed by the Government, as part of the new national land policy, out of the previous regional advisory services with their local colleges, and it includes various research institutes. It is to be developed into a standard service employing people of a more or less standard ability and knowledge in its various grades, and so supplying a product, advice, which will not vary very much from one area to another. It is claimed that within this comprehensive service knowledge will be diffused more quickly than between the old separate groups; new research will get known more quickly and already existing specialised knowledge will be more easily integrated on to any par-

ticular farming problem; in addition, there will be refresher courses for Advisory Officers and so on.

Success in these objects is a matter of administration and that is why the Service's success at the Royal is encouraging. But it is also a matter of psychological understanding, and, here again, what its spokesmen have to say is encouraging. So far they have avoided pronouncements which would make one think they had underrated the difficulty of popularising scientific knowledge among farmers. The emphasis has been on working "with" the farmer, not "for" him, still less against him. All experience of agricultural educational work shows that this is the only possible approach: you have to get the farmer mixed up in your ideas or he will not absorb them; otherwise, though the problem he has raised may have been solved theoretically, it will not have been solved practically. In fact, also, the Service itself will need the cooperation of farmers. It will have many new ideas to develop and they will require testing out in the ground. It will maintain experimental farms of its own, but it can never hope to cover a sufficiently wide ecological range for its "pilot plant" experiments without the cooperation of the farming community. In so far as the Advisory Officer is an experimenter and investigator, therefore, he will need to work with the local farmers; and where he is an innovator he will need to learn from them the effect of his novelties on farm management and economics.

No farmer can know enough, without advice, to get the full benefits of the application of modern scientific knowledge to his land, and it is to be hoped that enough of them will admit the fact to allow the new Service to develop its full impact upon our productivity and their profits. It is a free gift, indeed, to farmers, it is all honey. Naturally there is a sting; something will be expected in return. There are many other advisory services available to farmers in many other countries, but the significance of this British edition is, as has been said above, that it is part of the

national land policy. This policy provides for the expropriation of inefficient producers. In practice this will mean farmers of unjustifiably low productivity compared with the average. The declared object of the N.A.A.S. is to raise the average of productivity. So it will not do to get too far behind one's neighbours in the application of science to one's farming.

Scientists connected with agriculture, on the other hand, will find this large organisation less interested in the answers to some questions than in others and more likely to employ certain types of scientist than others. Practical need will determine the questions it asks and practical ability will be necessary in its employees. It is possible that in the long run agricultural science will be pretty well absorbed by the N.A.A.S., though that is nobody's intention at the moment. Or, to put the thing less controversially, agricultural research will be guided along certain directed lines in response to practical demand. Professor Scott Watson, Chief Education and Advisory Officer at the Ministry of Agriculture and head of the new service, gave, last January, "a random sample of the various fields of research" to "indicate what progress is being made and what gaps in our knowledge remain to be filled" to a conference in Edinburgh. Three items in his sample, trace elements, plant hormone synthesis and new varieties of potato, have already been talked about in *Science News* 3. It may be interesting to follow up issues related to some of his other items to illustrate his theme of "progress" and "gaps."

Fertiliser Placement

The seed of most crops is sown through drills, which deposit it in rows, whereas fertilisers are usually, in English practice, applied to the seed-bed through distributors which give an even covering over the whole ground. Apparently, therefore, much of the fertiliser is applied where, from the point of view of that immediate crop, it is not wanted, between the rows, particularly with crops which are sown

in wide rows, such as potatoes and sugar beet. This waste of fertiliser could possibly be avoided by depositing the fertiliser in bands close to the roots. There is another economy concerned here too. When calcium or nitrogen is applied to the soil, almost the whole of it is available for solution in the soil water and thus for absorption by the roots of plants. But a large proportion of any phosphate applied is transformed in the soil to compound forms insoluble in water, and is thus locked up and only becomes available for plant nutrition over a long period and partially. (That is, you can never hope to get back from the soil anything like as much phosphate as you have to apply to it.) Now this locking-up effect is reduced if the phosphatic fertiliser is not mixed generally with the soil, but is placed in narrow bands. Since phosphatic fertilisers are the great necessity for high yields in most British soils, this is important.

From a rather different angle farmers and manufacturers, aiming at the economy of a single operation instead of two, have for many years experimented with combined drills, capable of putting down the seed and the fertiliser in the one drilling. Such machines have been known in this country for at least a century and probably more. They were never satisfactory and an easier line of progress was found in the perfecting of the general distributor, after which interest in combined drills waned. Since the last war, however, the question has been taken up again. Manufacturers have made available combined drills capable of putting the fertiliser down with the seed. Scientists have asked themselves whether these bands of fertiliser are really best located in contact with the seed or a little away from it, and, if the latter, just where. Engineers have wondered how.

Engineers first. It is not so hard to arrange for fertiliser to be deposited with the seed, though there are tiresome problems, such as the corrosive effect of many fertilisers on mechanism and the varying physical condition in which

they end up after a short trip on the British railways and a few months' farm storage. But research into fertiliser placement implies machinery capable of depositing *accurate amounts independent of external factors*. Commercial drills are gravity-feeding, assisted by some sort of mechanism to keep the fertiliser running through: essentially they shake the stuff out. Their delivery rates, for various settings of the mechanism, will vary greatly according to the "condition" of the particular batch of fertiliser in question. You cannot get much further here because the "condition" of a finely powdered or even a granulated fertiliser is difficult to define in a useful way: it may be anything from the fine powder it was sent out as (rare) to a collection of different sized lumps. The rates vary according to humidity, but no relation can be established between the rates and the humidities. Gravity feeds, therefore, are no use for research into fertiliser placement: which prompts the reflection that eventually they will be rejected for commercial work, since the whole essence of this problem is accuracy of delivery, both in quantity and location. For research, the only reliable method of feed is by positive displacement. Here a piston rises in a cylinder filled with the fertiliser, which is then deflected down the feed tubes by scrapers. Thus the same *volume* of fertiliser is delivered each time. The *weight* delivered is slightly variable, because of differences of density in the fertiliser caused by being jolted over rough ground, by the vibration of the tractor, by compaction by the piston and, again, to a small extent by the condition of the fertiliser. The variability can be much reduced by running the machine for a bit before starting on the measured work, so that the fertiliser can settle down.

Thus, as so often in agricultural research, an immense amount of mechanical playing about has to be gone through before the investigation can really start. After that, there are really two questions:

(a) is there a significant variation in yield proportionate

to quantity of fertiliser used, according to whether it is generally distributed or is placed in bands?

(b) assuming that fertiliser should be placed in bands, what is the best position for those bands?

It is confirmed that, for *cereal* crops, phosphates sown down a combined drill in contact with the seed are about as effective as twice the quantity distributed generally, in average cases; and in phosphate-deficient land, considerably more so. Up to quite large quantities of phosphates and compound manures can be combined safely, without damage to the germinating power of the seed, which fixes the upper limit of the method. Less definite results have emerged from experiments with potassium and nitrogenous fertilisers. But *root-crop* seeds, excepting potatoes, very easily suffer injury from fertilisers, especially in dry weather, and fail to germinate. Combined drilling in contact with the seed is therefore not advised for these crops. Yet it is precisely for these crops, which are set in wide rows, that general distribution is most wasteful. Possibly, better results with roots may come from attention to the second point—what is the best placement for bands of fertiliser? The problem would then be to find a position for the bands to ensure the advantages of economy of fertiliser, stimulation of early growth and hastened ripening, without damaging the germinating seed.

The Americans have done a lot of placement work on the potato crop. As has been said, this crop is not susceptible to damage by fertilisers. Yet their conclusions are applicable to cereal, and possibly to other, crops which are. The following, amongst other, positions for the bands have been tried out: in contact with the seed; mixed with the soil in the row; above the seed; below the seed; at the side of the seed; at the side and slightly below: or again, 1 to 2 inches under; $1\frac{1}{2}$ inches above; mixed in the row; in the row not mixed; 2 inches to each side on the same plane; 2 inches to each side and 2 inches below seed level; 4 inches to each side on the same plane. The general conclusion has been

that fertiliser is best placed two inches to the side of the seed and either level with it or slightly below it. There is now, however, a question whether even higher yields of potatoes are not obtained by placing only a proportion of the fertiliser in bands, with the remainder generally distributed in the old way.

Placement of fertilisers is one of the means of securing higher output for less expenditure which we have neglected, though it has been incorporated into the farming practice of many countries. Thus the standard distributors used by American potato planters incorporate the findings of the scientists which have been mentioned above, but not so here. It is possible that research workers in this country have been a little daunted by the empirical nature of the problem as put to them. The fundamental chemistry of plant nutrition is not understood and therefore the line of progress is not clear. It is interesting, for instance, that the effect of "locking-up" phosphates, mentioned above, is not universal: it does not occur in many areas of Australia for example. If we could apply that fact to our conditions, we might cut our present expenditure on phosphatic fertilisers to one-fifth. But since scientists cannot yet explain that fact, they cannot yet tell us how to apply it.

Too Much Tinkering?

At recent meetings of cattle breed societies the thyroid gland has got rather more attention than is usual at these gatherings. This gland regulates the plane of metabolism in animals; so that the development of young beasts and the productivity of mature beasts can be stepped up, in many cases, by feeding either natural thyroxin or a synthetic substitute in the form of iodinated casein.* At present the method is experimental, but it concerns breed societies from two aspects. In the first place, they are concerned with questions of pedigree and performance in

* The chief protein of milk, treated with iodine.

a competitive context: they regulate records and establish the breeding backgrounds of various cattle families on which commercial pedigree values depend. Now Nora may be an inherently better cow than Dolly, but the latter, primed with iodinated casein, might outyield her significantly, and the use of such stimulants can upset rankings no end. Secondly they are concerned with a long-term view of the health of their breed, and nothing is more likely to ruin that quickly than ignorant use of endocrinology by semi-bankrupt farmers. Acting on these two points, one Society has provided that, while records of treated cows shall be accepted by the Society, they must be distinctively marked, so that everyone knows the cows have been treated; and has also urged the Ministry of Agriculture to ban the sale of iodinated casein pending the completion of the Ministry's long-term experiments with it, which are designed to test its effects on constitution. The general impression at the debates of the other Society seems to have been that there was "too much tinkering" with cows nowadays.

The practical man is in a dilemma. He must produce as much of his product, in this case milk, as cheaply as he can. But it is not much use producing double this year if your herd is going to fold up with exhaustion next year. That is, he must not depreciate his capital for the sake of immediate income. At the same time he has the feeling that the routines he has been brought up in are "natural", though the modern milk-cow is, logically speaking, an artificial animal leading an artificial life. But if his word "natural" is taken in the sense "what is proved by experience not to depreciate my capital", he is making a valid point, and his conservatism is not stupid. The experiments with iodinated casein, for instance, will not be concluded this year or the next. It is common sense for a working farmer to let someone else be progressive, because he cannot afford the risks. This is why scientific discoveries are not rapidly applied to agriculture.

Scientists are not so interested in what is "natural", though the N.A.A.S. will of course have to pay attention to what is economic. Another peculiarity they have is to regard animals as existing for one purpose: they like to divide cows into *beef* cows and *milk* cows. Now the farmer likes a cow which gives a lot of milk and then fattens up well for beef when he has to get rid of her: he likes a "dual-purpose" cow, which the scientist calls a "no-purpose" cow. If cows gave wool and laid eggs that would please the farmer, but not the scientist. His object is the reduction of the animal to its specialised purpose, in the case of the dairy cow the production of milk. This implies three things:

Physical efficiency in the conversion of foodstuffs to milk.

Elimination of secondary products.

Regularity of production of milk.

Considerable progress has been made under the first heading, but further progress depends on a better understanding of the processes of digestion in ruminants than is ours at present.* Farmers are provided with a useful working system whereby to calculate the food requirements of animals whether they are in production or not, and most of them would be satisfied with what they are told on this topic. It is possible to ration the animal under the two categories of maintenance and production—what is sufficient to maintain it in condition and at a stable weight, and what is sufficent to enable it do a certain measured amount of work directly, as with the horse, or in produce, as with the sheep, pig or cow, over and above remaining merely stable. *Maintenance* rations will vary with the kind of animal, its weight and the amount of surface it exposes to loss of heat. Thus a fat bullock weighing about 1,750 lb. needs about 20,000 calories daily, whereas a sheep, which has a larger surface in proportion to its weight and also operates

* See for a fuller discussion of this question *Penguin Science News* No. 3, p. 159

at a higher temperature, will require about 2,000 calorie per 100 lb. Similarly a 6 cwt. cow requires 6/9 as muc food for maintenance as a 9 cwt. cow, other things bein equal. Tables are available to show how much of an particular food will produce the required quantity o calories. *Production* rations are expressed in terms of the product desired, pound of flesh, gallon of milk, and so on For instance a cow giving three gallons of milk per day will require three times as great a production ration as one giving one gallon only, and here again the weights of particular foods to feed per gallon have all been worked out. If this knowledge is used by the farmer as intelligently as it has been presented to him, much waste of nutrients can be avoided and he has little need to complain about the digestion of ruminants. Scientists, however, are puzzled by various features which at the moment have slight practical application, but which might be important eventually. For instance, ruminants can digest cellulose. This in itself is something of a mystery, but the buffalo can live on rice straw and tree loppings. There is a future for any scientist who can persuade cows to digest cellulose as efficiently as buffaloes do. Ruminants also have a strange indifference to the amount of vitamin C in their diet: if it is short it is synthesised in the rumen and if there is too much it is destroyed. Simple nitrogen compounds like urea behave curiously when fed to ruminants. If fed pure or in solution they are quickly absorbed and excreted, but if fed in a close mixture with a cellulose material, part of the nitrogen behaves like protein or amino-acid nitrogen. These processes are not properly understood, because present ideas about ruminants' digestions are empirical.

Elimination of secondary products and regularity of production are matters for endocrinology and endocrinology is news, because it offers the exciting prospect of being able to gerrymander nature. The farmer's problem is to bring cows into milk, in the autumn, once every year. This entails production of a calf, which more often than not is slaugh-

tered soon after birth, and whose gestation detracts from the mother's milk production during the lactation preceding its birth. Calving in the autumn is made necessary by the winter-milk policy, since cows give most milk within 4 to 8 weeks after calving, on the average. Now the cow has a gestation period of some nine months. That is, to get autumn calvers you have to have them come on heat and be struck in the depths of winter, not intended by Nature for love, still less for artificial insemination. Many cows do not "bull" at all during the winter, or very infrequently. Heats last only a few hours, frequently between dusk and dawn, and may be almost without external manifestation. In the summer, by contrast, heats may go on for 36 hours or so and a great fuss is made by the cow for all to see. In practice heifers are usually calved down in the autumn fairly successfully, and as they grow older their calving dates move further and further through the winter into the spring, the natural time, but one when the price of milk sharply falls. This is the importance of stilboestrol, which was dealt with in *Science News* 1, page 86. A detailed explanation will be found in that number of the method of action of the product, whose effect is to start animals ovulating fairly energetically, so that one can see and catch them. It is in fairly general use, but does not act infallibly. If barren cows and maiden heifers could be brought into milk by injections of hormones or synthetic substances, they would not need to divert energy to gestation and could be made to produce regularly. It is feasible in the laboratory but not yet in the cowshed.

Thus the picture of the dairy cow is that of an animal being rapidly altered from all purposes except milk-production. The farmer says there is too much tinkering about with her and is scared of damaging his capital or the breed he is interested in. The scientist cannot get on unless he delimits and defines his objectives; moreover that is his intellectual habit; the cow must be specialised. The farmer's habit is to be ready to switch according to

the market: he wants to see a profit both at A and Z, not just at some refinement of A, unless it's a nice big one.

Destruction of Aphides

The general idea seems to be that DDT and Benzene Hexachloride will kill any insect for ever. They are certainly effective, especially against sucking insects such as lice and mosquitoes, but results of their application to aphides have so far been disappointing. Now aphides are currently described as the most serious pests of growing plants in this country and almost every crop has its particular aphis, such as the peach aphis, the potato aphis, the cabbage aphis, the large green aphis which feeds on peas, beans and clover, the woolly aphis of apples and the leaf-curling aphis of plums. There are about a hundred varieties which harm our crops and many more innocuous ones. The damage caused is familiar to everyone in its direct aspect. The plant loses its vitality as the aphides suck its nutrients and sap; it is poisoned by the saliva they inject into it, so that, for instance, the leaves become distorted in various ways; its leaves are covered with the sticky honeydew the insects have to void because they have taken up more sugar from the plant than they can use. Indirectly, aphides are a major factor in the transmission of virus diseases, for which their prodigious activity makes them very suitable. The annual loss caused by aphis-spread virus in the potato crop alone is estimated at something like £3,500,000 and the disease of sugar-beet known as "yellows", which we owe to the peach aphis, is one of the great limits to yield. These are only examples of a loss which, if it could be accurately estimated, would astonish most of us.

As has been said, aphides are not so susceptible to the new insecticides as some. Nor can they be controlled by the stomach poisons, such as lead arsenate, because they do not bite the surface of the leaves. (They insert their mouths, which are like tubes, into the channels in which the food materials of the plant are transported and suck

them up.) They can only be killed by contact poisons and vapours. They are easily killed by preparations of pyrethrum or derris, or by nicotine. The first two are applied as dusts or sprays and the third by fumigation, but the methods have in common their laboriousness and expense. Consequently they are not usually applied till the attack is seen to be bad—or rather, arrangements for applying them are not made until the attack is seen to be bad. By the time of applying, the infestation, which has a very short peak, may well be over, the damage done and not an aphis to be seen. Even supposing a successful attack on the infestation at its peak, no control has been achieved over virus diseases. The influx of aphides in spring builds up to its peak gradually and the dissemination of virus is continuous from the first. By the time the aphides are noticed the virus is there, though the symptoms of disease may not be yet apparent. This is a dismal tale, but fortunately the aphis is subject to parasites and predators, against which it has no defence. It is attacked by a minute wasp, which lays its eggs in its body, and by a fungus. It is eaten by ladybirds, by the larva of the dirty-looking wasp-like fly which hovers about in July and August (the hover fly) and by the adults and larva of the Lace-Wing fly. It is very delicate, and an infestation can be washed away by heavy rain.

Eggs of aphides can be destroyed in winter by the ordinary tar-oil or DNOC winter wash. The difficulty here is that many species do not lay their eggs on the plants of which they are pests. It is one thing to destroy next year's infestation of your orchard by spraying in the winter, but it is quite another, for instance, to try to spray all the common spindle trees, on which next year's infestation of your beans and beet is brewing up. The eradication of the spindle as a national policy has been discussed, but it would clearly be very laborious. Furthermore the aphis in question (aphis fabae) can lay its eggs on the guelder rose, and might merely switch. The eggs of this aphis, probably our most

damaging species, are invulnerable to any frosts experienced here and are not attacked by parasites or predators. Their survival till March, when they hatch, is therefore guaranteed. The unfortunate fact, however, has been turned to good use. If virtually all the eggs of aphis fabae to be found on the spindle tree in December and January will hatch, it follows that an estimate of the infestation of next year's beans and beet can reasonably be based on a count of the eggs. This hard work is carried out annually by the Advisory Dept. of the School of Agriculture at Cambridge. Spindle shoots from various parts of the country are gathered in the middle of the winter and a count of aphis eggs is made which, by careful comparison with records from previous years, enables surprisingly accurate forecasts to be made. Of course it is only a second-best: it would be much better to be able to kill the eggs.

The general point is, that in this particular matter of insecticides, where science has had some of its most publicised triumphs, no effective technique has yet been evolved against the most important pest, the aphis: there are remedies, but they do not amount to an economically feasible technique except in particular instances. It is an illustration of the practical difficulties which meet the agricultural scientist: he does not just have to kill a hundred aphides out of a hundred in a cage; he has to work at a distance through human psychology and economics, rebellious unpredictables. But we may still hope for results. Research, which is world-wide, has so far been more concerned to elucidate than to interrupt the complicated life-history of the aphis.

Problems of Nuclear Physics

BY PROF. R. E. PEIERLS, F.R.S.

1. *Introduction*

THE physicist, like the boy who takes his watch to pieces, is interested in what makes things tick. In taking things to pieces, the pieces get smaller and smaller, and the laws that describe their behaviour get more fascinating. At the beginning of this century we were learning how to dismantle atoms, and by about 1930 their behaviour had been understood in all important respects, though there are still now many points of detail to be explored. Meanwhile the most inquisitive people turned to the nucleus, the small core of the atom. Some insight into the nucleus has been gained already. We know what nuclei are made of and, like the boy with the watch, we have learnt to take nuclei to pieces and (unlike most boys) how to put them together again. We know a good deal about their behaviour in various circumstances, but we have yet to obtain a clear understanding of what precisely makes them tick.

Some of what follows overlaps with the recent article by Bethe ("Atoms and Nuclei," *Science News* 2, p. 19). Some of the gaps I shall have to leave can be filled in by reference to that article.

2. *What Are Nuclei Made Of?*

We know, first of all, that nuclei contain protons. These are small particles weighing practically as much as an atom of hydrogen, whose nucleus is just one proton. They carry a positive electric charge, and the charge on a nucleus depends on just how many protons it contains. We know there are protons in the nucleus since we can actually dislodge them from nuclei by hitting them hard enough

with suitable particles. The first example of this kind w Rutherford's discovery that the passage of fast alp particles from radium through air can dislodge proto from some of the nitrogen nuclei.

Similarly, we know that nuclei contain neutrons. Tl evidence is again the fact that we can dislodge neutroı from nuclei by suitable bombardment, a typical exampl being the production of neutrons from radium and bery lium, first studied by Bethe and identified by Chadwick Neutrons are particles with no electric charge, weighin about the same as protons (actually slightly more). Now i all nuclei are made of neutrons and protons and nothing else, one would expect that the weight of any nucleus should equal the weight of a suitable number of protons plus that of a number of neutrons. This is very nearly, but not exactly, true. Even for the difference there is an explanation in the law, which Einstein derived from the theory of relativity, that mass and energy are different forms of the same thing, or in other words, that energy has weight. When particles are bound together into a nucleus, energy is liberated, and work would have to be done in order to pry them apart again. This means that the nucleus has less energy than its parts taken separately, and according to Einstein's law it has also smaller weight. This "mass defect" is, therefore, a measure of how strongly the nucleus is held together. In fact, the comparison between its mass defect and the energy needed for breaking up a nucleus provides one of the most direct proofs of Einstein's law.

One would, therefore, conclude that nuclei are made of protons, neutrons and nothing else, but here we meet a difficulty. Protons and neutrons are not the only things which can come out of nuclei. It is known that radioactive nuclei can also emit beta rays. These consist of ordinary (i.e., negative) electrons or in some cases of positive electrons. Must we not, therefore, conclude that the nucleus contains a store of positive and negative electrons as well as neutrons and protons? It is the present view of physicists that this is

not the case, but the reasons for this need some explanation.

3. *Where Do Beta Rays Come From?*

The situation can perhaps be compared to that of the scientists in the old days who observed that you could get fire from coal and who concluded that the coal and other fuels contained a substance which they called phlogiston, which could come out in the form of a flame. Nowadays we do not talk of the fire being in the coal but we think of it as a phenomenon which is produced by the reaction of coal with the oxygen of the air. We might think then that electrons are not stored in the nucleus but are produced by the transformation that takes place in a nucleus when it undergoes the so-called beta decay. The notion of material particles like electrons being produced is somewhat surprising at first, but there are other cases in which this is by now a familiar phenomenon.

It is known that electrons can be produced in pairs, one positive and one negative, by the passage of radiation through matter. If gamma rays (i.e., very short-wave electromagnetic radiation) of sufficiently high frequency pass near an atomic nucleus, one finds pairs of positive and negative electrons created. According to Einstein's law, the amount of energy which equals the mass of two electrons is just about one million electron volts (or MeV, for short). In other words, in order to produce pairs from artificially produced radiation, one has to employ a machine giving energies well above the million-volt region. Conversely, the collision of a positive and a negative electron can lead to their destruction, with their mass being converted into radiation. If we had matter containing a lot of free positive and negative electrons, this destruction would continue quite rapidly until there were either no more positive or no more negative electrons left. This is the reason why we never find any positive electrons occurring free in nature unless we catch them when they have just been produced by some suitable process.

4. *Why do Electrons not fall into the Nucleus?*

We must then not regard electrons as indestructible, but this would not yet exclude the possibility of their existing inside a nucleus. It is, however, very difficult to imagine that electrons could exist inside nuclei. The reason for this is that on the laws of quantum theory, i.e., the laws which have been found to govern the motion of electrons in atoms, it takes some definite energy to force an electron to move in a limited region of space. This is substantially the reason why atoms can exist at all. On the laws of "classical" mechanics, which covers the motion of bodies of a reasonable size, the electron would be capable of losing more and more energy by approaching closer and closer to a positive charge, such as an atomic nucleus. This energy would be given out in the form of light and in other ways, until the electron had fallen right into the nucleus. On the quantum theory there comes a point when the attraction pulling the electron towards the nucleus is not strong enough to confine the electron to a still smaller region, and for this reason atoms of finite size can be perfectly stable. To confine electrons to a region, not of the size of an atom, but of the size of a nucleus, would require an energy larger in proportion to the inverse square of the diameter of that region. Since the diameter of a nucleus is about ten thousand times smaller than that of an atom we would require an energy about 100 million times larger than atomic energies. The electrons could be stored inside nuclei only if there was a force capable of producing several hundred MeV on the approach of an electron. It would then be a strange coincidence if the force should just be sufficient and not a little too much. One would in this case expect the net gain in energy, i.e., the difference between the work done by the attractive force and used up to confine the electron to be a reasonable fraction of the total. Actually, however, nuclear binding energies are only of the order of a few MeV. This is the order of magnitude of the work needed to confine a heavy particle, such as a neutron, to

a region of nuclear dimensions and it looks, therefore, rather more reasonable to suppose that the motion of heavy particles only is involved in forming a nucleus.

Another and perhaps more important argument is this: in certain cases it is possible to increase the charge of a nucleus by one unit by means of the impact of a proton, which gets caught in the nucleus and dislodges a neutron, so that a charged particle has been substituted for an uncharged one. The resulting nucleus has more charge than is good for its weight and tends to reduce its charge by beta decay in which a positive electron is emitted. If after this we add one or more neutrons, the nucleus may now be too heavy for its charge and increase it by the emission of a negative electron. We can now remove the spare neutrons, for instance, by bombardment with fast particles, and in this way return to a nucleus of the same weight and charge as the one we started with in the beginning. The net result is then that, apart from putting protons and neutrons into the nucleus and taking them out again, we have obtained a negative and a positive electron, and if these had come from a store inside the nucleus, the nucleus must now be that much poorer in electrons. However, the nucleus which we have obtained will be in all appearances the same as the original one and we can, in fact, go on repeating this experiment indefinitely. Since there can hardly be an unlimited store of electrons inside, we have to conclude that at least some must have been produced in the process, and it is then more satisfactory to think that, in fact, all of them have been so produced.

5. *Doubts about Neutrons and Protons*

Once we have accepted the idea that not everything that comes out of a nucleus must necessarily have been inside to begin with, should we review our conclusion that neutrons and protons are inside? Here we seem on much safer ground, since these are nearly 2,000 times heavier than the electron, so that the production of even only one

neutron would involve an energy of the order of a thousan MeV. These amounts of energy are not usually available i nuclear transformations and while the production of heavie particles is, no doubt, possible in principle, it cannot tak place in those transformations in which we usually observe the emission of protons or neutrons.

However, while the production of heavy particles is difficult, this is not necessarily true of a change in their nature. The neutron has about the same mass, i.e., it has about as much energy as a proton, and from the point of view of energy alone it should be quite easy to change the one into the other. We know, however, that electric charge cannot be created or destroyed, and hence if a neutron becomes a proton some positive charge must be disposed of or some negative charge used up. This is precisely what happens in the process of beta decay when, for example, a positive electron is produced. Since in this process the charge of the nucleus must go down one unit, a proton must have converted itself into a neutron. Another possible process is that a proton becomes a neutron, the charge being balanced by another neutron converting itself into a proton, i.e., the net result is that the two particles exchange their nature. There is reason to think that such an exchange is a very common process inside a nucleus, although the evidence for it is very circumstantial and there is as yet no very direct experimental confirmation. The question could be settled in the following way: if a very fast neutron collides with a proton it is likely to be deflected from its way by only a small amount and to give only a small velocity to the proton which it has hit. One would then expect that the passage of very fast neutrons through hydrogen should result in only a small spreading of the neutron beam and in weak recoils of the protons. If, on the other hand, the proton and neutron had a strong inclination to change their rôles, the neutron which proceeds on its way would now have become a proton and vice versa, so that we would expect the protons to go forward

and neutrons to stay behind. In the extreme form which I have described, this effect probably would require neutrons of energies of the order of 100 MeV, which are not at present available for measurements. But even at 20 or 30 MeV one expects a tendency of more protons or more neutrons to go forward, and such measurements would, therefore, settle the question of the proton-neutron exchange.

If this exchange is really a very frequent phenomenon it may not be possible to keep the identities of the particles clear while they are strongly interacting. It might still be possible to look at some point inside a nucleus and to say "Here is a heavy particle" but it might be rather more difficult to say with certainty whether what we have picked up was a neutron or a proton.

To summarise, we have so far seen that nuclei do not contain electrons and that they contain protons and neutrons, the total number of each kind being known from the known weight and charge of the nucleus, but possibly with their identities getting somewhat confused.

6. *Nuclear Forces*

What are the forces that hold the parts of the nucleus together? They can certainly not be electric forces, like those that confine the electrons in the atoms, for two reasons. First, because all the particles either have no electric charge or a positive one. Since like charges repel each other, this would never lead to attraction. Secondly, we need forces which are very much stronger than electric forces would be in regions of the size of a nucleus. A light nucleus is about 10,000 times smaller than a hydrogen atom, and since Coulomb's law says that electric energies go inversely as the distance between the particles, one would expect electric energies in the nucleus to amount to 10,000 times atomic energies, that is perhaps to a few hundred thousand electron volts, whereas nuclear binding energies are of the order of several millions.

There must, therefore, be a new type of force acting between these particles, and one can see at once that these must be "short-range" forces, that is to say, they must diminish with increasing distance more quickly than electric forces. Otherwise the interaction, in ordinary conditions, of two pieces of matter a fair distance apart should depend not only on their electric charge but also on the type of nuclei which they contain. This is not the case.

Indeed, the study of a collision between two protons (observed by letting beams of fast protons pass through hydrogen) confirms precisely the laws calculated on the assumption of purely electric forces as long as the protons are slow enough. With reasonably slow protons, i.e., of energies below about 1 MeV, the electric repulsion will prevent them from approaching closer than within 3×10^{-13} cm., which is just about the mean distance between particles inside a nucleus.

When, however, the proton energy rises beyond this value, strong anomalies are found in the scattering which can be explained only by assuming that a new attractive force begins to act at about that distance. Similar results have been obtained from the interaction of neutrons with protons at low energies.

A good deal of information has been collected about the force between a neutron and a proton. Some of it comes from the study of collisions between neutrons and protons (passage of neutrons through hydrogen). More can be inferred from the properties of the deuteron, i.e., the nucleus of "heavy hydrogen," which is made of just one proton and one neutron.

This nucleus plays the same important part in nuclear physics as the hydrogen atom (one proton and one electron) in atomic physics. Unfortunately, while the hydrogen atom has a series of excited states which give rise to distinctive spectral lines which could serve to test any theory, the deuteron has no excited states, since the forces are only just sufficient to hold the two particles together in their normal

state. Any extra energy given to them is sufficient to tear them apart.

We, can, however, study the way in which the deuteron breaks up, for example, under the effect of gamma radiation, and also the reverse process, the capture of a neutron by a proton, when the surplus energy comes out in the form of gamma rays.

As to the forces between two protons, the scattering of protons by hydrogen has already been mentioned. A collision between two neutrons cannot be observed with present techniques. What we know about neutron-neutron forces comes from the following reasoning. Compare two nuclei such as helium 3, containing two protons and one neutron, and hydrogen 3, with two neutrons and one proton. Their masses and other properties are so similar that one can conclude that their only difference is due to the electric charge on the extra proton, and the slight difference between neutron and proton mass, but that the nuclear force between two protons and that between two neutrons is the same. This conclusion is borne out by similar comparisons in all other cases where data exist.

More evidence on all these forces can be obtained by studying the binding energies of heavier nuclei, but here the evidence becomes more circumstantial and is not so easy to summarize.

In this way it has been possible to form a fairly close estimate of the range of the forces, i.e., the distance over which they are effective, and of their strength at close approach. The precise law of variation of force with distance, however, is not yet known at all accurately.

7. *Refinements*

In studying, for example, the scattering of neutrons by protons, it is found that some neutrons are scattered in a manner quite different from what one would have expected from the forces which we deduced from their interaction in the deuteron.

This apparent contradiction has been shown to be due to the fact that nuclear forces depend on the spin directions of the two particles. In quantum theory each particle, such as an electron, proton or neutron has a "spin," as if it were revolving about its own axis with constant speed. The spins of two such particles which collide, must always be either in the same or opposite directions.

It turns out that the force depends on whether the one or the other is the case. The attractive force is stronger if the spins are parallel, and this is the case in the deuteron.

For opposite spins the attraction is not strong enough to give a bound state at all, and no deuteron in which the spins are opposed is possible.

Moreover, the proton-neutron interaction may depend on whether or not the two particles happen to be in exactly the same state of motion.

To understand this, we must remember the possibility mentioned before, of the two particles changing their rôle, or what amounts to the same, proton and neutron changing places. This exchange process is not possible if they are in different places since it would involve a sudden jump. So the exchange can take place only if the particles are as nearly in the same place as, within the laws of quantum mechanics, we can tell. Similarly they must be moving, as nearly as we can tell, with the same speed. If this exchange process contributes at all to the interaction energy of the particles the resulting force will therefore be different according to whether the particles are in the same state of motion or not.

In the case of two like particles, say two protons, this distinction does not arise, since there is a strange law in quantum mechanics, discovered by Pauli, according to which two like particles can never be in the same state of motion and also have parallel spin. This law leads to the known structure of the atom, in which only two electrons (with opposite spins) can be in the most stable orbit or "K-shell", two in the next higher one, etc. Hence for like

particles the question of exchange does not arise, and the only refinement here is the dependence on spin.

We believe that the laws of quantum mechanics which have been found applicable on the atomic scale, are also valid in the nucleus, and that only the nature of the forces acting between these particles is different. If this is right, then, if we could only find out exactly what the forces are, we could work out what the properties of any particular nucleus should be. At the present this programme is held up for two reasons. The first is that our knowledge of the forces is still very crude. The second reason is that once we deal with any problem involving more than three or four particles, the purely mathematical complications in solving the problems, assuming the forces to be known, become almost prohibitive. In fact, already the problem of three or four particles is very terrifying even to a mathematician with a high degree of skill and courage, and only lately very ingenious methods have been devised that allow us to deal with these problems with quite a reasonable effort.

The situation is even more complex than the above picture would indicate. It had always been taken for granted that the force between two particles was a "central" force, i.e., one pulling the one particle in a direction towards the other or away from it, but there is no reason why this should always be the case.

If the forces were such central forces, one would expect most nuclei to be spherical in shape, and in particular in the deuteron one would expect the neutron and the proton to run about each other so that the line joining them would be equally likely to point just in any direction in space. This means that the region occupied by the proton or neutron on the average would again be a sphere. However, very ingenious experiments by Rabi and his collaborators on the effect of electric fields on the deuteron have revealed the fact that the deuteron is not spherical in shape but elongated like an egg. This must be due to forces

which tend to push the neutron and the proton into a certain direction relative to each other. Once the existence of such "non-central" forces was discovered one had to see how much of the mathematical work done previously with central forces could still be trusted. This process is still going on, but again the fact that we have no information of the precise nature of the forces and, for example, their dependence on the distance between the particles, is a serious handicap.

8. *Nuclear Reactions*

From what I have said so far, one might gather that, until we have a better knowledge of the nuclear forces, we cannot describe in detail what goes on inside a nucleus. That is not a correct impression, since it turns out that many of the properties of nuclei, and in particular the nature of nuclear reactions, is not at all sensitive to the precise nature of the forces, so that there is a good deal we can understand even on the basis of our present vague knowledge of the forces. It all adds up to a rather satisfactory picture, which was built up following the ideas of Bohr. What we know is that the nucleus behaves rather like a drop of liquid, roughly spherical in shape, or somewhat egg-shaped to be precise, with the density much the same for heavy or light nuclei. On being disturbed, for instance, by a collision with another particle, the matter inside the nucleus is set into irregular motion. This is violent even if the colliding particle was very slow, since the short-range attraction speeds it up on its final approach to the nucleus; it therefore arrives with a proper impact. Like a billiard ball that collides with a cluster of other balls on the table, the particle shares out its energy with all the others and in general none of them is left with enough speed to overcome the attraction and get away. Whether in the subsequent motion one of the particles happens to pick up enough speed to get away, is a matter of chance; in any case it will take a little while before this happens. Until it happens,

the nucleus holds together like an atom or molecule and, just as in those cases, definite energy levels or quantum states are prescribed for the nucleus. In this way there exist fairly sharp energy levels for a nucleus even when its energy is high enough for one of the particles in it to get away. The result of a collision depends, then, very much on whether the extra particle arrives with a velocity that will leave the combined nucleus, with this new particle added, with an energy just equal to one of the quantum states. In this case one speaks of "resonance". If there is no resonance the extra particle will not be able to get into the nucleus at all.

The description of nuclear reactions depends, therefore, on the position of the resonance levels and their properties. Their precise position, of course, cannot be predicted without a very reliable knowledge of the forces, but about their general properties quite a lot can be found out. For instance, we can study the way in which the result of a collision depends on whether the energy is very exactly equal to that of the resonance level, or whether it is a little different from it. The results have been found to agree very well with the general theory and this confirms the belief that the general laws of quantum theory hold for the nucleus as well as for the atom.

9. *Meson Theory of Forces*

So far I have talked about the forces between nuclear particles as something given without enquiring where they come from. Let us turn for a moment to the atom by way of analogy. We know that an atom is held together by electric attraction, which is governed by Coulomb's law about the attraction of opposite charges. This means two electric charges held at a distance from each other attract or repel each other, as the case may be, and this can be verified easily on a larger scale in the laboratory. It is not satisfactory, however, to think that a body can exercise a *direct* influence on another at a distance, without bringing

in some means by which this effect is transmitted from point to point. In the case of electric forces this is, in fact, described by Maxwell's idea of the electromagnetic field, which exists at any point in space and which transmits disturbances locally. In the same way, for instance, the turning of a light switch in your house does not have a direct effect on the lamp, which may be some distance away, but it causes a change in the voltage of the conducting wires nearby, which will be transmitted from place to place until it reaches the lamp.

We know also that such electromagnetic disturbances travel in empty space with the velocity of light, and light is simply a particular form of such a disturbance.

Now, in the quantum theory a light signal cannot be sub-divided indefinitely, but consists of finite units, so-called light quanta, or "photons", each carrying an amount of energy proportional to the frequency of the light wave of which they form part. These behave in many ways as if they were definite particles. Only, since massive particles could never move with light velocity, they are particles without mass and they can never be stopped without making them disappear altogether.

Things are quite similar as regards nuclear forces. One would again look for a kind of field which transmits the force between, say, a neutron and a proton, only in this case the particles into which such a field can be resolved cannot be particles without mass. If they were, the law for the forces would come out precisely the same as that for electric forces, and we would then not be able to account for the existence of short-range forces. If, however, we assume that this field is made up of particles with a finite mass, then we obtain short-range forces; in order to get the right sort of range we have to assume that their mass is about 200 times greater than the electron mass, or in other words about one-tenth of that of the proton. Such particles then are intermediate in mass between those previously known, and they are now called "mesons". The

reasoning I have given here is substantially that used by the Japanese Yukawa in 1935, and shortly afterwards it was discovered that particles with just about that mass existed in cosmic radiation. These particles were found to carry one unit of electric charge like the electron or the proton. There may also exist similar particles without charge, but they would be much harder to detect.

Just as electric forces arise from the possibility of one charge giving out a light quantum and the other accepting it, the nuclear forces would require the possibility of one particle giving out a meson and another absorbing it. If this involves charged mesons then, for instance, a positive meson could only be given out by a proton, which in the process would turn into a neutron, and it could only be taken up by a neutron, which would thereby become a proton. In this way the overall result is that the two particles have changed their nature and this leads in a natural way to the exchange forces which I have described before. The same mechanism, however, will not produce any interaction between two protons. To account for proton-proton and neutron-neutron forces, we have to postulate that there exist neutral as well as charged mesons.

This meson theory of the nuclear forces is extremely attractive, but there is as yet no direct evidence in its favour. Recent experiments, in fact, make it likely that the picture is a good deal more complicated than appeared at first. For example, recent work at Bristol by Powell's team has proved that in cosmic rays there exist at least two kinds of mesons with somewhat different weights, and that the heavier one can change into the lighter one, part of the mass difference being set free as energy.

In any case it has not yet proved possible to work out consistently the consequences of the meson theory of the forces, since this needs the application of the methods of quantum theory to a continuous field. Already in the case of the electromagnetic field this proved to be one of the most stubborn problems of modern mathematical physics,

and while many people have tried to overcome the difficulties, no satisfactory solution has yet been found. It is not surprising that the same difficulties have appeared in the case of the meson field and that they, too, have so far defied any attempts to solve it. It is becoming more and more likely that what is needed here is not just a slight mathematical refinement of our existing methods, but something completely new and important.

Whether this new step forward will ultimately be developed by altering our description of the known facts and thereby bringing order into them, or by new discoveries of phenomena of which nothing is yet known, remains to be seen.

There is in any case no doubt that our knowledge of all these problems will make an enormous step forward when physicists succeed in accelerating particles to energies of several hundred MeV, since it is then likely that one will be able to produce mesons at will, rather than work with the scanty supply provided by the cosmic rays.

10. *Beta Decay. The Neutrino*

I have already referred to beta decay, i.e., to the possibility of a nucleus changing its charge and producing an electron (positive or negative) in the process, but there is more to it than that. One would have expected all the electrons coming out of a given type of nucleus to have the same velocity, so that the energy they take away would just balance the energy change in the nucleus. But very early in the work on beta rays it was found that electrons from any substance undergoing beta decay covered a very wide range of velocities. This might mean that either the nuclei from which the electrons came, or those left behind as a result of the process, had varying energies, but in all other ways all nuclei of a given type appear quite identical, and, for instance, no variation could be detected in their weight. By studying the energy balance in other reactions involving the same nuclei, it was established that the energy

would just balance for the fastest electron that occurred in the beta process. Whenever an electron with less energy came out, and this was in the overwhelming majority of cases, some energy appeared to have got lost.

Physicists were very reluctant to think that the law of the conservation of energy might not apply in this case, since this law was of such fundamental importance and had been established in so many other parts of physics.

The alternative is to assume that the missing energy is given out in some new form, in which it escapes detection. The hypothesis was proposed by Pauli that an unknown particle with no electric charge and of small mass was produced together with the electron. Fermi, who carried this hypothesis a good deal further, gave this particle the name "neutrino".

There is another reason to believe in the existence of this new particle. I have explained that electrons, protons and neutrons each have a spin, even apart from their rotation about each other. Quantum theory teaches that the spin of each particle is just one-half of the smallest angular momentum that two particles can have when revolving about each other. Let us consider a nucleus of which the total number of neutrons and protons combined is an even number. Its spin, therefore, consists of an even number of half units or, in other words, a whole number of units, plus the effect of their motion which again gives a whole number of units. After the electron has been thrown out as a beta ray the total number of neutrons and protons has not changed, so the total spin is still a whole number, but the electron has now carried away one half-unit of spin. The motion of the electron contributes whole units and cannot, therefore, make up for the discrepancy. This process would, therefore, violate the conservation of angular momentum, which is as basic as the conservation of energy. If there is a neutrino it would be perfectly reasonable to expect it also to have half a unit of spin like the other particles and this would immediately remove the trouble.

So far, however, evidence for the neutrino is entirely circumstantial. It is true that the Fermi theory gives quite a satisfactory description of such details as the velocity distribution of the beta electrons, but one would like to be able to pick up a neutrino occasionally, instead of only losing them all the time. Now it is quite true that if neutrinos can be thrown out by a nucleus, it must also be possible to catch them again, but both are very rare phenomena. Beta decay is very slow compared to the times taken by other nuclear reactions, and one must, therefore, expect the reverse process, i.e., the capture of a neutrino, also to be very rare. On the Fermi theory, a neutrino could indeed go very many times across the interior of the earth and still have practically no chance of hitting anything on its way. This makes the neutrino a very elusive particle, but no physicist will give up hope that one day a method might be found by which to show it up.

11. *Conclusion*

It would have been much easier to write this article fifteen years ago. Then our knowledge of nuclei made a very much tidier picture. There were fewer elementary particles and it appeared likely that the remaining gaps in our knowledge about them could be filled rapidly. We now know that this was due to our ignorance, and that these gaps contained a wealth of new facts which we then did not even suspect. A new landscape has been opened up and it will take us time to find our way about in it, but just this bewildering variety of new things makes nuclear physics one of the most exciting branches of Science to-day.

Diatoms

BY N. INGRAM HENDEY

Where They Are Found

THE study of diatoms has been tied necessarily to the development of the microscope as an aid to vision, and many of the early records are confused and unreliable. It seems quite certain, however, that the famous Dutch observer, Antony van Leeuwenhoek, was engaged in correspondence with English observers concerning the wealth of minute living organisms which the microscope revealed, and the first published description of a diatom was given by an unknown English microscopist as early as July 5, 1703. This account, in the form of a letter to Leeuwenhoek, together with an accurate illustration, appeared in Philosophical Transactions of the Royal Society (1703). The unnamed writer had examined a drop of pond water which contained the common Lemna or "duck-meat" and had observed diatoms attached thereto.

Diatoms are to be found practically speaking wherever there is water and an adequate amount of light. Freshwater forms are found in every pond, stream and wayside ditch, in all parts of the world. They are found in the mountain-top lakes of Titicaca in Peru, at an altitude of 10,000 feet, and in the thermal springs of Yellowstone Park and of Kamchatka, where the temperature of the water is more than 50°C. Another section of the freshwater flora inhabits the thin film of moisture that invests soil particles. *En masse*, diatoms appear as a greenish-brown scum floating upon the surface of the water, or as a film covering mud or stones at the bottom of ponds, ditches, etc. Others form frondose colonies and attach themselves to plants or debris in the water. The marine flora extends over all the oceans

from the polar ice cap to the tropics, and constitutes th largest vegetable element in the vast floating fields o microscopic life referred to as "plankton".

All diatoms are unicellular, and each individual cell capable of carrying out all the vital functions of life, an reproduces by the simple method of fission. They liv mainly free and unattached, but some species link them selves together to form chains, or live within a speciall secreted mucous sheath or envelope and assume th appearance and habit of a small filamentous seaweed attaching themselves in like manner to larger object immersed in the water. One species in the Antarctic inhabits cracks in the skin of the whale, while another is found in oyster beds. Most species are very sensitive to the chemical and physical factors of their environment, and truly fresh-water species never are found living under marine conditions of the open sea, and vice versa, although a brackish water flora exists which has a considerable toleration for sodium chloride and is found sometimes in fairly fresh waters, as well as in coastal waters, particularly in estuaries.

Diatom productivity in the surface waters of the great oceans shows a very marked seasonal variation. Two clearly marked maxima are to be observed, one in the spring, and the other in the autumn, the former being the more intense, particularly in polar waters. The limiting factors are not always the same for different areas, but it appears that the exhaustion of nutrient substances, such as phosphates and nitrates, and available silica for structural purposes may inhibit diatom growth. During periods of great diatom activity the surface waters may become so densely populated that sea birds alighting in search of food frequently get their feathers so clogged that they are unable to rise again. When the organisms die the tiny cells sink slowly, the organic material becomes disintegrated by bacterial action, and the siliceous frustules (their characteristically sculptured shells) collect on the floor of the ocean to form a deep-sea ooze. During geological time deposits of considerable thick-

ness accumulate, and cataclysmic movement of the earth's crust may raise the floor of the ocean and cause the waters to be drained away, leaving the diatoms high and dry, often to be overlaid by lava, volcanic ash, or some other geological formation. The superimposed layers exert a pressure upon the diatom deposit and compact it into a hard rock-like substance. Vast deposits of fossilised diatomaceous earth exist in many parts of the world, the more important ones being in Germany, Algeria, Kenya, and California. In Britain small deposits have been found in the Kentmere district and in certain islands off the west coast of Scotland. The Californian deposits are among the largest and purest in the world and attain a thickness of more than 1,000 feet over a very considerable area. Some idea of the geological time required to form such a deposit, and the number of organisms involved, can be gained by realising that after death, small organisms such as diatoms would take several years to fall to the bottom of the ocean, and that each cubic inch of diatomaceous earth would contain something like 60,000,000 cells.

Structure of Diatoms

Viewed under a high-power microscope, diatoms are not at all plant-like in appearance, for there is no differentiation of parts into stem, leaves or roots, as in ordinary plants. Each plant consists of one single cell microscopic in size, varying from 4 microns up to 500 microns in diameter, or let us say from 1/6000 inch up to 1/50 inch. These dimensional extremes are enjoyed only by a few, while the bulk of the species recognised (there are about 15,000 sorts in all) vary from 25 microns to 200 microns in diameter, that is, from 1/1000 inch to 1/125 inch approximately. The cell is basically the same as the cells of the higher plants and contains the central, all-important nucleus suspended upon a network of protoplasmic strands, accompanied by a number of coloured bodies, called chromatophores. These chromatophores are often flattened kidney-

shaped, or roughly spherical bodies, and contain the chlorophyll, a green pigment common to most plants, together with a brown pigment called diatomin. These two coloured substances control the photosynthetic processes by which in the presence of sunlight the plant is enabled to form nutrient materials necessary to its life. The chromatophores may be regarded, therefore, as laboratories in which complex organic foodstuffs are produced from relatively simple substances. All these elements are contained within an extremely tenuous membrane, the perizonium. Thus far, the diatom cell is very like that of any other plant, but differs from it very markedly in the following respect. The diatom deposits an outer coating of non-crystalline siliceous material, a white substance allied to quartz. This outer coating or frustule, as it is called, is quite hard and rigid, and is deposited in a perfectly symmetrical mannèr. The frustule is really a box, composed of an upper and lower lid, each fitted with a girdle band around the edge. The upper lid and girdle is slightly larger than the lower, over which it fits, in the manner of the lid of a pill-box. The two halves, or valves as they are called, are otherwise identical in all respects.

The shape of the frustule may vary considerably. Many of the marine ones are circular, or broadly oval, others triangular or quadrangular, while most of those which live in fresh water are boat-shaped. The surface of the silica frustule is exquisitely ornamented with radiating or curved lines, which may be thickenings in the silica, or more often, perforations through it. These markings are characteristic of the species. Most of the markings are very difficult to see, even with a good microscope, and in some species they lie at the limits of resolution in white light, that is, the lines are in the neighbourhood of 125,000 to the inch. The electron microscope has placed in our hands, however, a new powerful tool, which shows that many of the perforations have an internal plate, which is again perforated, the ultimate perforations being of the order of 100 Angstrom

units in diameter, or somewhere in the neighbourhood of 1/2,500,000th of an inch. Whatever the true nature of these markings proves to be, they are arranged over the surface of the frustule in an endless array of design, which makes the diatom one of the most beautiful objects in the natural world. The existence of infinite beauty in Nature, particularly in microscopic things well below the range of normal vision, has always been a subject for speculation. In the diatom the structure is undoubtedly functional, that is, the perforations have a job to do (see below), but no apparent reason is immediately forthcoming for the arrangement of the performations in the form of a pattern. Here structure is arranged to produce a design. The endless pattern may be functional also, in an obscure way, but for the moment it appears that Nature is utilising Design without Reason.

One extraordinary feature of the design upon diatoms is the precision with which it is reproduced. It was stated earlier that the diatom frustule was in the nature of a pill-box, and when the cell is about to undergo reproduction the lids of the box move apart slightly until the edges of the girdles are almost parting company. This movement of the valves brings about an increase in the internal capacity of the cell by adding to its depth. Nuclear division then takes place, and the daughter-nuclei take up positions at opposite ends of the cell. The protoplasm divides and surrounds the two newly-formed nuclei and two new valves are formed inside the mother-cell. When the formation of the new valves is complete, the two daughter cells part and continue a separate existence. Thus each diatom consists of one old valve and one new one. Generation after generation, throughout many millions of years, the design which is characteristic of the species is faithfully reproduced. It will be seen also that as the daughter-cells are formed *inside* the mother-cell and that the two new valves are the lower and smaller ones, repeated division is attended by a gradual reduction in size. This reduction in size, or rather in diameter, is not allowed to proceed too far, for a sexual process

usually intervenes which brings about a re-establishment of size. It appears therefore that diatoms start their life fully grown and that the size of new cells is limited by the size of the parent cells from which they spring, for once the rigid silica framework is deposited and the design determined, no growth that would require an increase in diameter is possible—the only growth that is permissible is brought about by deepening the girdles of the valve, that is, on an axis at right angles to the valve surface.

In outline, diatoms have exhausted every shape, exploiting three basic forms, often combining them to produce infinite variety. Let us consider some of these forms. Firstly there is the naviculoid or boat-shaped outline, where the ratio between length and breadth varies to produce everything from that which is needle-shaped to that which is broadly oval. Examples of this form are seen in Plates 23 – 27. This type of outline is predominant in freshwater diatoms. Secondly, there is the truly circular outline; this is modified to produce broad ellipses as well as ovate and panduriform outlines. Thirdly, there is the polygonal outline. Forms possessing three, four and five angles are common, while others possessing up to 21 angles have been discovered. Forms in the last two categories are more common in marine waters, the polygonal ones being particularly numerous in the great fossil deposits of the Miocene. Examples of circular diatoms are seen in Plates 28 – 33, and of polygonal ones in Plates 34 – 38.

These examples have been chosen not because their beauty is any more marked than that of others, but because they show clearly the types of structure employed by some of the most common species, representing both living and fossil floras.

Recent research into the structure and physiology of diatoms has indicated that the siliceous frustule of the organism is not merely a rigid covering surrounding the soft and vital protoplasm in order to protect it, but that the perforations through the valves of the frustule permit

interchange between the cell contents and the aqueous medium in which the organism lives. This peculiar perforate structure may account also for the movement of diatoms. Movement in living diatoms is restricted mainly to those forms which are boat-shaped. These forms possess a central mid-rib with lines of perforations arranged with reference to it. This movement, one of the most fascinating phenomena to observe under a microscope, has mystified microscopists for a very long time, for it takes place in complete absence of any visible organs of locomotion. The tiny boat-shaped cells move either in a graceful glide, or in slow hesitant jerks, proceeding half majestically or half comically in their watery world, propelled as it were by unseen hands. It may be that the diatom forces water from the cell through the perforations in its siliceous skeleton, causing the organism to move forward. If this is the explanation of the curious method of locomotion, it means that Nature has forestalled Man in the discovery of jet propulsion.

Economic Use of Living Diatoms

The rôle of micro-organisms in Nature varies considerably and is determined to a large degree by whether the organism is a plant or animal. The diatom, being a microscopic plant, forms part of the "producer population" and is concerned during its lifetime with building up complex foodstuffs from simple substances. This building up, or synthesis, is accompanied by a liberation of oxygen, and the process results in a twofold general enrichment of the surrounding area. Soils in particular, whether of the kitchen garden or the corn-producing prairie-lands, depend very largely for their productivity upon their microbiological content, and surface soils rich in diatoms tend to favour the germination of young seedlings.

The diatom population of surface waters may act in a somewhat similar manner. The large diatom community supported by lakes and reservoirs liberates oxygen into the surrounding water, thereby aerating and purifying it. This

is the normal activity of all green plants in water, such as Duckweed, Canadian Pond Weed and such other plants which form a green film over the water, but as the seasonal maxima for diatoms occur in the very early spring and late autumn, before and after the other forms of pond plant life, diatoms act beneficially by prolonging this purifying period, as well as by adding to its intensity.

The rôle of the diatom in reservoirs of drinking water is somewhat complex and deserves more detailed attention. The main problem of such undertakings as the Metropolitan Water Board is to provide water suitable for human consumption. The water must be of good physical quality and free from obnoxious substances which would impart an objectionable taste or smell. More important still, the water must be free from pathogenic bacteria which might be injurious to public health. In order to ensure the requisite standard of purity a complicated system of filtration and chlorination has been introduced together with biological control of reservoirs and constant chemical and bacteriological examination. To the water engineer, the presence of diatoms in the reservoir may be a blessing or a curse. Reservoirs which derive their water from a cultivated area such as the Thames basin are rich in nitrates, phosphates and silica and are liable to great outbursts of diatoms during the spring. For example, a population density of more than twenty million cells per litre would not be unusual. When the organisms die, the cells disintegrate and liberate vast quantities of organic substances which greatly favour bacterial development, resulting in a rapid consumption of oxygen. One result of an oxygen deficiency is an increase in the growth of anaerobic bacteria and fungi which may give rise to unpleasant tastes or smells and render the water undrinkable. Another aspect of the same problem is that upon the death of the diatoms, the siliceous frustules put an additional strain on the filters. A reservoir supplied by Thames water with a volume of nearly seven million gallons, might contain anything up to 110 tons of

the diatom *Fragilaria crotonensis*, measured as a dry weight. Such an immense diatom swarming would involve a daily removal from the water by filtration of an amount of diatom silica equal to one ton, dry weight. Such enormous quantities of plankton diatoms in the reservoir cause trouble by blocking filters, particularly of the "rapid" or "pressure" type. Slow sand filters, on the other hand, owe their efficacy almost entirely to their biological components, one of the chief being the diatom. These slow filters are usually exposed to light, and filtration is effected by the water passing through a skin or film of diatoms and bacteria. The diatoms collect mainly on the surface of such a filter and render a great service by producing oxygen as a by-product of their photosynthesis. This assists in the oxidation of organic materials and prevents the lower layers of the filter becoming anaerobic, and fosters the growth and development of oxygen-requiring bacteria which in various ways improve the palatability of the water.

The diatom population in the marine plankton is most important, as it plays a vital part in the economy of the seas, for not only does it oxygenate the water, but becomes the basic link, the grass as it were, in the food chain of all the other creatures which live in the sea. Whales, for example, travel southward from their breeding grounds as the ice breaks up, in search of the great plankton fields, the grazing grounds of the far south. Here, just as much as in the English countryside, the richness of the pasture decides the fatness of the herd. The plankton diatom also plays an important rôle in oceänographical research. Diatoms serve as indicators of the direction of flow of the oceanic currents in which they live, and in the South Atlantic particularly, the diatom has helped very considerably to plot the position of the convergence-zones of the various masses of water which go to make up the South Atlantic and Southern Oceans.

One other economic aspect of living marine diatoms will be considered, that is, the part they play as fouling

organisms upon the hulls of ships. When any surface is immersed in seawater, under natural conditions, it quickly becomes fouled with marine organisms. The algal fouling of ships at the waterline by a green seaweed, usually a species of Enteromorpha, is a sight common enough to all who have visited docks where ships lie at anchor, but often, far down below the water-line the hull may be fouled by a strange assemblage of creatures. Amongst these may be found the barnacle and the tube worm, whose outer coatings form hard chalky concretions, together with delicate colonies of hydroids such as Tubularia and Obelia and soft bodied, jelly-like Tunicates. This fouling does very little actual damage to the metal structure of the ship, but increases surface friction, which retards the vessel as it moves through the water. In order to overcome increased friction due to fouling, more fuel must be used if the rate of speed is to be maintained. It is estimated that on a heavily fouled ship an increase of fuel consumption of up to 40 per cent may be required. This, in peacetime is a serious drain on fuel stocks, and in times of war even more so; further, loss of speed due to fouling may result in the loss of a valuable convoy or may adversely affect a naval action. To prevent marine fouling, ships and dock installations are usually painted with an anti-fouling composition. Anti-fouling paints contain, amongst other things, toxic substances, such as compounds of copper and mercury, but their exact mechanism is as yet imperfectly understood: probably the toxic salts leach from the painted surface, and act as protoplasmic poisons. Research has shown that not all marine organisms are equally sensitive to copper and mercury, and that certain species of diatoms are highly resistant. This means that a freshly painted surface may be leaching sufficiently highly to repel the more sensitive organisms, such as the settling stages of barnacles or hydroids, but will permit successful colonising by the resistant diatoms. These diatoms, finding themselves in a

position where they do not have to compete for living space, and in which they are more or less free from attack by organisms seeking them as food, tend to multiply rapidly and form together with bacteria a slime film upon the submerged surface of the ship. Observations have shown that an anti-fouling paint which favours the production of a heavy slime film tends to protect against the attachment of barnacles and other fouling organisms. In this manner it may be said that diatoms themselves act as anti-fouling agents.

Fossil Diatoms

Enormous beds of fossil diatoms are found in various parts of the world. They are the floors of the long-forgotten Tertiary seas which covered parts of North America and Central Europe some 60 million years ago. The majority of these Tertiary beds are associated with basalt lava flows, which in many instances lie both above and below the diatomaceous strata. Until comparatively recently it was believed that the most ancient and most prolific period of diatom growth was during the transition from Mesozoic to Tertiary, and that a peak was experienced in the warmer Miocene seas. Recent work, however, by Dr. G. Dallas Hanna of the California Academy of Sciences, has proved the existence of a large diatom flora in the Moreno shale, a well defined Upper Cretaceous stratigraphic unit extending along the west side of the San Joaquin Valley, in the Panoche Hills, California. Deposits of fossil diatoms are known by several names, the most common of which are diatomaceous earth, kieselguhr, molera and diatomite. Although diatomaceous earth occurs in most countries, it is worked commercially in but a few, as most deposits are small in extent or of impure quality, and could not be operated economically. The United States of America is the world's largest producer of diatomaceous earth, and Algeria is probably the second largest. In California the deposits are almost continuous between Los Angeles and

San Luis Obispo, reaching a maximum in the Lompoc area. The purest of these are marketed under the trade names of *Filter-cell, Super-cel* and *Hyflo super-cel.* Diatomaceous earth is used either in blocks cut from the natural deposit without further treatment, or it may be crushed, calcined to remove organic impurities, and graded by air-blown separators. When thus purified it is a white or creamish white substance resembling chalk. It occurs in nature in varying degrees of purity, and the following analysis of an air-dried Canadian sample gives a good idea of its percentage composition.

Silica (SiO_2)	83.20
Alumina (Al_2O_3) ..	3.80
Iron Oxide (Fe_2O_3) ..	3.00
Lime (CaO)	0.80
Magnesia (MgO) ..	2.23
Potash (K_2O)	0.89
Soda (Na_2O)	0.33
Water and organic matter	5.26

Economic Use of Diatomaceous Earth

The chemical and physical properties of diatomaceous earth make the material admirable for many scientific and industrial purposes, the most important of which are

(1) filtering medium
(2) insulator against heat, cold, and sound
(3) catalyst carrier
(4) absorbent
(5) filler
(6) building material
(7) abrasive
(8) pharmaceutical preparations
(9) stratigraphic indicators

Filtration

In many industrial and commercial undertakings, filtration is an important process, and the filtering medium should be insoluble in the liquid to be filtered, chemically inert,

and should be selected so as to ensure clarity of the filtrate together with a high rate of flow. The greater part of the diatomaceous earth used as a filter-aid is absorbed by the sugar industry, and in the clarification of beer, cider, wines and other fermented liquors. Large quantities are used also in the chemical industry for filtering dye-stuffs, varnishes, pharmaceutical preparations, oils and fats. In large-scale operations, it is the usual practice first to build up a "pre-coat" upon the cloths of the filter-press, and then to incorporate a small amount of the diatomaceous earth with the bulk of the liquid to be filtered, keeping the whole volume well agitated to prevent settling. This ensures that an efficient barrier of filtrant is built up in the filter-press, and that prior to the actual filtration, the diatoms in the bulk of the liquid have an opportunity to come into contact with and absorb the extremely fine non-rigid or colloidal particles which otherwise would pass through the filter. The shape and size of the diatom skeletons is of the utmost importance to the efficient use of diatomaceous earth as a filter-aid. Material which contains a predominance of small forms of uniform size and shape, would tend to pack tightly together and so prevent an even or sufficiently high rate of flow; conversely, material with a predominance of large and regular forms would tend to lie too loosely, and would make for too rapid filtration and would fail to remove the finest impurities and so give rise to a cloudy filtrate. For efficient filtration, diatomaceous earth should contain particles in the correct size relation so that the interstices should vary down to that size particle which is the largest to be allowed to remain in the filtered liquid. In order to obtain these conditions, it is found that a diatomaceous earth should contain a mixture of the elongated or rod-shaped diatoms, and the circular or discoid ones, together with a certain proportion of fragmentary matter to obtain the necessary size gradient of the interstices.

Small-scale filtration problems, such as removing con-

taminants from engine lubricating oils, may be dealt with successfully by employing "by-pass" filtration. This system does not maintain completely clean oil in the engine, but restricts contamination to a steady figure, the value of which is dependent upon a combination of the proportion of the total oil which passes through the filter at each circulation and the efficiency of the filter. One of the most efficient filters of the "by-pass" type is the Metafilter.

The filter consists of a pressed steel cylinder through which passes a central slotted tube which serves as the oil outlet, and upon which is fitted the filter element. The element consists of a number (about 80) of specially constructed units each of which consists of two embossed discs of filter paper joined together at the periphery and separated at the centre by two thin metal washers. The discs are 4 in. in diameter, and are furnished with a central perforation which allows them to be threaded upon the outlet tube. The contaminated oil introduced through a specially baffled nozzle at the top of the cylindrical casing, is forced to circulate through the system under pressure, thereby effecting partial filtration of the oil at each circulation. The efficiency of the filter depends upon the fact that the paper discs are heavily impregnated with diatomaceous earth, and the ingenious construction of the filtering element offers a total filtering area of approximately 14 sq. ft.

This type of filter maintains a very high rate of flow, and the use of diatomaceous earth ensures a high degree of clarity in the filtrate. Plate 40 shows the skeletal remains of diatoms recovered from one of the specially prepared components of the Metafilter. Examination of the forms present indicates that the diatom material used probably was obtained from the Miocene of California.

Insulation

Diatomaceous earth is used for insulation either in the form of natural bricks, sawn from the deposit in the mine, bonded bricks, or as a granular powder. Considerable

quantities for insulating purposes are mined in Jutland, where it is known as "molera". Here again, successful use of the material depends upon proper consideration being paid to the size and shape of the diatoms contained therein. The low thermal conductivity (approximately 0.000127 gramme-calorie-seconds at 200°C) of a diatomaceous earth, containing a preponderance of large unbroken forms, makes it one of the best insulators for temperatures below dull red heat. Insulation at higher temperatures calls for material in which there will be increased porosity due to an increase of the fine perforations or air-spaces per unit volume of the material. This is probably due to the fact that at high temperatures there is a high rate of radiation and convection through air, which increases markedly with further rises in temperature. It follows, therefore, that insulation at high temperature is best obtained by using diatom material in which predominate very small uniformly shaped cells of the same size, through which pass the greatest number of perforations.

Diatomaceous earth from parts of Central Europe and from New Zealand are admirably suited for this purpose. It follows also that solid impurities such as silt or powdered quartz will act as conductors and will lower the insulating value of the material. Diatomaceous earth may be used not only for insulating against heat or cold, but also against sound. Bricks sawn from the natural deposit may be used to line telephone kiosks, libraries and audition rooms of broadcasting studios, where it will perform the dual role of fire-proofing as well as insulating. The problem of using diatomaceous earth for insulation has been dealt with but briefly, but its general application in this field is very extensive. The material may be used in powder form or in natural or bonded bricks or slabs for steam plant equipment, for lagging pipes and boilers, in smelting furnaces, in ceramic plant equipment, for lining kilns or enamelling furnaces, and in many other ways where it is desirable to provide insulation against loss of heat. Plate 41 illustrates

diatoms found in "molera", the Jutland deposit, so extensively used in the form of refractory bricks, sawn from the natural deposit.

Catalyst Carrier

Diatomaceous earth is used as a catalyst carrier in the hydrogenation of oils for the manufacture of soap. A soluble salt of nickel is mixed with a quantity of diatomaceous earth, sodium carbonate is added, and the mixture boiled. The product of the reaction is passed through a filter-press where the plates retain the earth together with the nickel carbonate formed by the reaction. The filter cake is removed, dried and heated to 300° C. in an atmosphere of hydrogen, where the nickel carbonate is reduced to the state of a finely divided black powder. This powder is then transferred to the vats of oil, and hydrogen is passed through under pressure. These conditions induce a hydrogen atom to be transferred to the oil, converting the oil into stearine.

Absorbent and Filler

The low apparent density and high porosity of diatomaceous earth makes it an excellent medium for absorbing dangerous or corrosive liquids. It may be used, therefore, to pack strong mineral acids, bromine, etc. It is used extensively to carry disinfectants and deodorant substances and has been used with some success as a carrier for fungicides and fertilising agents. Diatomaceous earth was employed to absorb the nitroglycerin in the original form of dynamite. About 25 per cent of the inert material was required, but this amount reduced the explosive strength of the mixture and for this reason it was replaced by wood-pulp, and various carbohydrates.

In the powdered form diatomaceous earth is used extensively as a filler or distributor in the manufacture of a large number of products. It is used in this connection in the manufacture of rubber articles, plaster, papier maché,

blotting paper, linoleum, etc. Perhaps the greatest quantity is used as an extender in the manufacture of paints. Diatomaceous earth has the property of imparting "flatness" to paint surfaces without modifying the tints, and large quantities are used in the manufacture of undercoats for enamels, and for the white paint used for traffic lines upon tarred roads. Diatomaceous earth makes the paint more porous, thereby facilitating drying, and its chemical nature offers greater resistance to exterior conditions.

Building Materials and Abrasives

It has been claimed that as long ago as the sixth century B.C. the Greeks and Romans used diatomaceous earth as a building material, in order to decrease the weight of certain structures, and that in 522 A.D. blocks made from it were used to build the dome of the Church of Hagia Sophia in Constantinople. In modern practice it is usual to mix a small proportion of the earth with cement in order to increase the strength of concrete. From 2 to 4 per cent is the proportion usually employed. It is claimed that the strength of the concrete may be increased by 40 per cent in this way. The compressive strength of the concrete reaches a maximum after about three months ageing.

Diatomaceous earth is used extensively as a mild abrasive. Incorporated in a variety of vehicles it forms an important part of many furniture creams, motor car polishes and household cleaners. Because of their different structure, diatoms from freshwater deposits are usually considered to be tougher and harder than those from Miocene marine deposits, and for this reason are preferred for the manufacture of metal polishes. Specially selected air-floated diatom material has been used with success in the manufacture of tooth pastes and powders, which owe their efficacy to the minute frustules of these marine plants.

Pharmaceutical Products and Cosmetics

The practice of medicine calls constantly for research

into the use and application of a wide range of substances. In the treatment of many skin diseases a chemically inert base is required to act as a diluent for potent medicaments, and one of the most successful is prepared diatomaceous earth. Specially selected material of the highest quality is used to carry such substances as ichthyol, resorcin, mercurials, benzoates and salicylates for the relief of the strange and distressing skin affections so common in tropical countries. The modern craving for glamour, particularly the kind which comes out of a box, provides many uses for diatomaceous earth. In the manufacture of face powder, it is perhaps one of the most suitable substances. Its high absorptive properties make it an excellent carrier for the various pigments which impart the all-important "shade" to the product, and provide a most suitable vehicle for the perfume which is said to convey such "allure" and "mystic charm".

Stratigraphic Importance

From a geological point of view, diatoms provide much interesting information. Diatoms fossilise easily and persist throughout geological time showing little or no signs of decay, and provide an indelible record of the past history of the earth's crust. A close study of the type, structure, abundance, and position of the diatoms in the strata provides data to the field geologist concerning climatic conditions, the degree of alkalinity or acidity, salinity and pH of the water in which they lived millions of years ago.

The close proximity of some of the largest deposits of diatomaceous earth to oil-bearing strata of the same or a closely related geological age, particularly in California, led to the belief that the diatom was in some way responsible, in part at least, for the occurrence of the oil, and it is now accepted by a large number of experts that the asphaltic oils from Miocene strata most probably were derived from this source.

Medical Front

Rh Factor

ONE of the big advances in medicine in the last twenty years has been the growth in our knowledge of blood diseases. The symptoms of anaemia, lack of red blood, are now known to arise in one of three sorts of ways – through nutritional deficiency (e.g., lack of essential dietary iron) or failure of the bone marrow to make red cells, through bleeding, through excessive internal destruction of red cells (haemolysis). Some diseases are characterised by destruction of red blood: malaria is one such. If the destruction is very rapid, the red pigment (haemoglobin) set free in the body is not removed quickly enough and lingers for a time in the skin and eyes as a yellow colour—one of the origins of the symptom of jaundice. When blood of a wrong (incompatible) group is given in a blood transfusion, the unsuitable red cells are clotted together and broken by agglutinins in the patient's circulation, and the liberated colour may cause a transient yellow.

Jaundice in the newborn child has been recognised as a distinct, puzzling, disease since about 1902 when a Birmingham doctor reported "a family series of fatal and dangerous cases of jaundice of the newborn—fourteen cases in one family, with four survivors". This report was followed by others from various physicians, for instance from another Birmingham man came "A series of fatal cases of jaundice in the newborn occurring in successive pregnancies". As time passed and knowledge extended, it became clear that one of the causes of the death of the unborn child within the womb was this same condition with the symptom of jaundice. Sometimes it caused illness or even death after birth, sometimes if more severe it killed before birth. Further, it seemed to get worse and worse in a series of

pregnancies in one mother. Her second child, shall we say would have severe jaundice but live, her third be born prematurely and perhaps die, her fourth be a real miscarriage, and her fifth pregnancy collapse when barely half completed.

The causes of jaundice are many. However, after thirty years of study it became clear that this jaundice of the newborn is due to haemolysis: something destroys the infant's red cells, and this poison is the cause of all the trouble. But what sort of a poison it could be, and where it was coming from, seemed for the time an insoluble question.

As so often happens, the answer came from research along a slightly different track as the result of a chance observation. In 1939 two American doctors gave the mother of a still-born child a blood transfusion of her husband's blood, and noticed a severe reaction. Although husband and wife both belonged to Group 0, the husband's blood upset the wife, and very careful test showed that her serum in fact agglutinated his red cells. This observation led them to suggest rather brilliantly that the mother had become immunised against a new red cell antigen or blood group substance possessed by her dead child who inherited it from her husband. The following year, a world authority on blood groups, an Austrian doctor working in New York, tracked this new red cell antigen down.

He had been studying the relationship between human and monkey blood groups—which, incidentally, is one way of finding out which monkeys are our closest cousins. He prepared antibodies (by injection into guinea pigs and rabbits) to the red cells of the Rhesus monkey. That is to say, something in the blood serum of the injected guinea pig would now agglutinate and haemolyse Rhesus red cells. These antibodies were now tested against the red cells of humans—normal American white people, and it was found that 85 per cent of those tested were like the Rhesus monkey: their red cells also agglutinated, and therefore contained a similar blood group factor to the monkey.

They were therefore called Rh-positive. Like other blood groups, it is inheritable.

The explanation of jaundice of the newborn is now clear. The father is Rh positive, the mother Rh negative. The child inherits the Rh factor from its father, and starts to give its mother Rh antigen. She forms antibodies to this "foreign" blood group substance, which go back to the child and destroy its red cells. Research in the last four years has confirmed, but complicated the picture. There is not *one* Rh, but several; the process is controlled by at least three inheritable genes.

For practical purposes, however, the explanation is adequate to forewarn the ante-natal clinic. The coming of the illness can be predicted and watched for. If necessary, the birth of the child can be brought on a month early, to lessen the danger from the mother's antibodies. But the research is not over, for we cannot yet prevent the disease. The mortality is perhaps 30 per cent instead of 50 per cent as formerly, an improvement certainly, but in time Science will do better.

Skin Disease and Psychology

Dr. G. G. Robertson has published several papers on the relation between ill health and mental outlook. The latest of these contributions to what is sometimes grandiloquently termed "psychosomatic medicine" appeared in the *Lancet*, July, 1947, and deals with dermatitis. He reminds us first of the case of Job, reported in the Bible. Job was a very rich man who regarded his wealth as the just reward for leading an upright and honest life. When his flocks and herds were stolen, his crops burnt, and his seven sons and three daughters killed by a whirlwind, he could not understand why apparently God had forsaken him. All his life he had walked in the ways of the Lord, and wealth had been his just reward; but now, inexplicably, it was gone. It was beyond his comprehension and his body began to itch and ooze intolerably.

Dr. Robertson quotes a number of similar cases from his own practice, where apparent injustice coincided with the onset of an intractable skin disease. A girl who had worked for five years in a tobacco factory got a dermatitis of her hands, which would not clear up. Enquiry demonstrated that the illness began when her forewoman had taken an unreasonable dislike to her and begun to make her life a misery. She was transferred to another department of the same factory, handling tobacco as before, and the skin then got better in a few days. A man was taken from his own work and sent to a shipyard by the Ministry of Labour, and it seemed to him that the only reason for this change was the pleasure minor civil servants got out of wielding their authority and pushing workers about. Within two months he got a cut on his leg which would not heal, and a dermatitis above it, which would not respond to treatment, until he returned to his old job, when it all got better.

It is important not to make the mistake in cases of this type of supposing that the illnesses were somehow deliberately brought on by the patients, who did not wish to get better. Quite the reverse was the truth, but the skin illness appeared to arise under the stress of deep grievance, and to get worse as the emotional difficulties were enquired into and brought out. When the grievance was remedied, or the patient realised the connection between his grievance and his illness, he got better.

We know little, scientifically speaking, about the relations between emotion and illness, and what we know is really old knowledge, like the case of Job. But it has got forgotten under the spate of new drugs and new physiology, and only now is being rediscovered and re-developed, as our full ignorance is realised.

How Penicillin Works

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How Penicillin Works

Every day, in hospitals and clinics all over the world, millions of units of penicillin are used to treat disease: yet nobody knows how the drug acts. It is a fact that it kills

certain sorts of disease bacteria (Gram-positive organisms such as streptococci and staphylococci), but the precise way it initiates the irreparable disorganization we call death is still unknown.

This is not for want of laboratory study, which has clarified the problem a little, recently. One can watch under a microscope what happens to a bacterial cell after treatment with a drug. One can measure its respiration, or power to ferment or digest foodstuffs, or its growth rate, or reproduction by division into two cells, before and after treatment with penicillin. All this has been done, and two facts, but only two, emerged. The first was that penicillin does not harm resting cells. As long as the living bacteria are just "ticking-over", respiring, growing a little perhaps, but *not dividing*, they can go on living. Penicillin somehow steps in when they divide. And that is the second fact: as soon as they have divided in the presence of penicillin, they are doomed. Wash all the drug away and give them a rich nutrient medium—it makes no difference; somehow the damage is done and they must all die. But the direct experimental approach has been of no further help. These doomed cells, although in some way changed by the penicillin, continue to respire, digest, grow normally for a time, and then slowly decay and dissolve. The immediate change wrought by the antibiotic has not been detected.

That at least was the picture until recently, when Dr. E. F. Gale and his co-workers at Cambridge while pursuing another line of work made an interesting relevant discovery. They have been studying for some years the chemical changes bacteria can produce in amino-acids, the component parts of the proteins of protoplasm. First they studied the different ways the bacterial cells broke down or digested these amino-acids, and then they used their new knowledge to begin the more fascinating problem of how the amino-acids are joined together by the cells to make proteins; or in other words, how living things make their own protoplasm.

They chose to study one single amino acid at once, so as not to complicate the results, and they chose glutamic acid because it was easy for them to measure it. One of their first discoveries was that some bacteria accumulate a great reservoir of free glutamic acid inside their cells, and then slowly draw on this store for building protoplasm and other uses. Even though there is only a very dilute solution of glutamic acid in the medium outside the cells, they are able to snap it up and get a very strong solution inside. Out of interest they did experiments on a great range of different sorts of bacteria, and found that it was only the Gram-positive organisms which show this glutamic acid concentration and store. It is also the Gram-positive organisms which are killed by penicillin. Was there a connection between the two facts?

There was. Bacteria treated with penicillin can no longer snap up glutamic acid and make a store. Once they have divided, no more amino-acid comes in, and they must live on this reservoir alone. Gradually that level drops, until finally there is insufficient to support further life, and the cell dies, from the effects of glutamic-starvation so to speak.

So this has pushed a little nearer that mysterious first effect of penicillin which is the fundamental one, and still undiscovered. How the cell manages to accumulate its glutamic pool has been the new point of laboratory study, and although a great deal of the mechanism is now known, none of it is affected by penicillin. The subtle piece of the living cell that is changed by the drug has not been tracked down after all. Perhaps the effect on glutamic acid accumulation is not so near the heart of the matter as was hoped, but it still seems a good lead. At the same time, we have to remember that at the time of writing (September, 1947), a great many more changes and events occur from moment to moment inside a living cell than we know how to observe or measure. Glutamic acid metabolism is only one facet of life. Penicillin may really be striking elsewhere.

Glutamic acid is much in the scientific news. In bacteriology, one interesting discovery is that the capsule around the Anthrax bacillus, which probably protects the germ from the body's defences, and so makes it a disease-producer, is chemically a polypeptide composed entirely of glutamic acid molecules, linked together or polymerised into very long molecular chains. A chemical substance of this particular nature has never been known before. In experimental psychology, it is claimed that rats given liberal amounts of glutamic acid in their food become much more intelligent than the average run of rats in learning and solving the way out of mazes. It is suggested that they do not get enough of this normal food component, present in all meat and protein foods, in the stock diets, and consequently cannot think so well. Certainly glutamic acid has some important but unknown role to play in the chemistry of the brain. According to a recent result the brain can manage with less sugar (glucose) if given glutamic acid as well—and if this is true it is the only substitute known.

These results with rats, and other researches, have encouraged doctors to try to improve the intelligence of children in the same way, and to try to control epilepsy (petit mal) with doses of the amino-acid. Preliminary results are encouraging, but sceptics will point to the long list of past epilepsy cures, boosted for a time and then discarded. There are years of work still ahead. We must know a good deal more about glutamic acid and why it is so important. We have only got to the threshold of knowledge so far.

Glaciers

BY DR. M. F. PERUTZ

ABOUT one tenth of all the land surface of the globe, comprising almost six million square miles, is permanently covered with ice. If all the ice in the polar regions melted and flowed into the oceans, the sea would rise by about 150 feet and submerge a large proportion of the fertile land on this earth. Without the steady flow of meltwater from the Alpine glaciers which act as tremendous reservoirs, the levels of some European rivers might be subject to violent fluctuations, with the result, for instance, that many hydro-electric power stations might have to be idle for a large part of the summer, unless huge artificial reservoirs were constructed.

Interest in glaciers in the past, however, has owed little to utilitarian motives, and most of the men who explored them have been enthusiastic amateurs, attracted by love of adventure and the beauty of the mountains. The beginning of interest in glaciers coincided with the growing consciousness of Nature during the 18th century, and was at first confined to naturalists who lived in the Alps, at a time when travellers from the lowlands still regarded the mountains as a horrible and fearful wilderness. One of the first to bring glaciers to the attention of the educated world was Horace-Bénédict de Saussure, Professor of Philosophy at Geneva, in his charmingly written *Journeys in the Alps* which appeared in 1779.[1] During the 19th century, observation of the glaciers developed hand in hand with the exploration of the Alps by mountaineers and scientists, but experimental work involving accurate measurements did not get into its stride until the 1880's, when the first text-book of glaciology also made its appear-

tell of people who vanished in them, never to be seen again. Actually the depth of crevasses in the Alps does not seem to exceed 100 feet and is usually very much less, while the total depth of Alpine glaciers may be of the order 1,000 feet or more (2,700 feet has been recorded in one locality). The lack of sounds from objects dropping into crevasses is often merely due to a deep layer of soft fluffy snow covering the bottom (Plate 6).

The frequency of crevasses is closely related to the speed of glaciers which in turn is a function of their size and slope. Thus the Upernivik Glacier, one of the gigantic ice-streams emerging from the Greenland ice-cap, advances at times by 125 feet per day, which is as much as a smaller Alpine Glacier covers in a whole year. Owing to their great speed, the surfaces of some of the large glaciers in Greenland and in the Himalayas are riddled with crevasses and broken up into seracs (ice-towers) to a degree that makes human progress over them exceedingly slow and tedious. This relationship between the frequency of crevasses and the speed of glaciers can readily be understood, since it was found that any increase in absolute speed also increases the differences between the relative speeds of different parts and hence magnifies the stresses on the glacier surface.

In part, the great velocities of the Greenland glaciers are probably due to their ending in the sea, where they can flow free from external friction. On the other hand, if glaciers approach the sea at a steep slope and with high velocity, their buoyancy gives rise to stresses large enough to cause the sudden fracture of enormous ice-walls which collapse and split up into fragments amid thunderous noise and great eruptions of spray. These fragments then drift into the ocean as ice-bergs. All ice-bergs, in fact, originate from glaciers, and most of those in the North Atlantic come from Greenland, but fortunately only a small proportion of the 130 cubic miles or so of ice-bergs which that sub-continent annually produces ever reaches the shipping lanes.

Advance and Recession

Glaciers are rarely in equilibrium—the annual accumulation of snow hardly ever exactly balances the loss of ice through evaporation and melting. Usually either the one or the other factor predominates, and as a result the glacier-end either advances into the valley or recedes from ground formerly occupied. Large advances and recessions of the order of miles usually take years or even decades and are the results of long-term climatic changes, but small fluctuations of the order of 100 feet may occur in any year for no apparent reason. Sometimes one glacier advances and another in a neighbouring valley recedes during the same period, and in single seasons such variations can often be attributed to slight differences in the local distribution of snowfalls. At present, however, the great majority of glaciers all over the world are going through a period of rapid recession and many smaller ones are dwindling away, a phenomenon which will be discussed in greater detail in the section on glaciers and climate.

At this stage we are more concerned with the actual mechanism of advance and recession than with the climatic changes which cause them. A surplus of snow accumulation and a consequent increase in the thickness of the glacier may result in a gradual increase in the velocity of flow, followed by an advance of the glacier-end. Sometimes, however, events take a far more spectacular course. It appears that some glaciers do not at first react to a gradual increase in thickness, which may continue for a number of years without being accompanied by a corresponding increase in velocity. Then, suddenly, the pent-up masses of ice break out and form something like a tidal wave which propagates itself along the glacier, causing an enormous increase in the velocity of flow. In the case of one glacier in the Tyrol, for instance, Hess calculated that the total thickness of the glacier at the crest of the tidal wave had not risen by more than a quarter, yet the motion of the glacier had been speeded up by a factor of 16. On such occasions

glaciers may advance very fast and even bury under them pastures, trees and houses, rather like streams of lava.

The reasons for this catastrophic turn of events cannot be understood without going more deeply into the mechanism of glacier flow.

THE MECHANISM OF GLACIER FLOW

Conflicting Theories

We have seen how de Saussure's picture of the glacier sliding down as a rigid cake became untenable as a result of the discovery of streaming motion, made by Agassiz and Forbes in the 1840's. The apparent contrast between the rigid and the fluid properties of ice, which scientists at the time found so disturbing, suddenly seemed to find a ready explanation through Faraday's discovery of *regelation*. This may be described as follows.

If a kilogram of ice is compressed at 0° C. and no heat is allowed to enter or leave the system, there results a melting of 0.064 grammes of ice and a dropping of the temperature by 0.0075° C. for every atmosphere of pressure that is applied. This is a fundamental fact which can be predicted from the laws of thermodynamics. Its discovery led Faraday to the following interesting experiment: if two blocks of ice at 0° C. are pressed together under water of the same temperature, some of the ice at the points of contact will melt as a result of the pressure, and at the same time the temperature at these points will drop slightly below 0° C. On release of the pressure, therefore, the surfaces of the ice blocks will be sufficiently cold to cause the film of water between them to freeze, thus sealing the two blocks together. By this means, a block of ice which has been broken apart can be sealed together again; hence the name regelation. To Tyndall, Helmholtz, and others this experiment seemed to provide the clue to the plasticty of ice in glaciers.

Roughly, their theories all assumed a melting of ice under local pressure leading to the formation of a crack; this

was to be followed by shear along the crack and healing of the crack through regelation. The various schemes differed in points of detail, but none of them proved entirely satisfactory. We can realise to-day that it would have been impossible in the middle of the last century to furnish a better explanation for the plasticity of ice, considering how little was then known about the nature and physical properties of crystals in general. At the time, however, people were sometimes less conscious of the weaknesses of their own theories than of those of their colleagues, and as a result they engaged in a series of violent disputes. Thus Tyndall, in his book *Glaciers of the Alps* concludes a critical examination of the theory of James Thomson, brother of Lord Kelvin, with the none-too-flattering comment:

"In short, this theory, as it presents itself to my mind, is so powerless to account for the simplest facts of glacier motion, that I feel disposed to continue to doubt my own competence to understand it, rather than ascribe to Mr. Thomson an hypothesis apparently so irrelevant to the facts which it professes to explain."(4)

Gliding and the Atomic Structure of Ice

In 1888 McConnel and Kidd made a discovery which seemed, at least temporarily, to resolve the deadlock over the theory of glacier flow. They found that lake ice yielded plastically to shearing stresses, even at temperatures far below the melting point, provided that a component of the stress was parallel to the plane of the original water surface. Though the important bearing of this experiment on the mechanism of glacier motion was appreciated at the time, its full significance did not become clear until 40 years later, when W. H. Bragg and W. H. Barnes discovered the arrangement of water molecules in an ice crystal with the help of X-ray analysis.

The simplest form of ice crystal is a prism with a hexagonal base, as shown in Fig. 6a. In order to see the

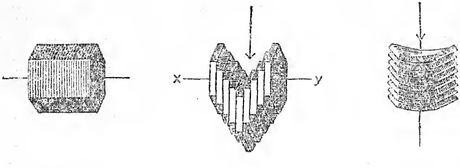

Figure 6

(*a*) Hexagonal ice crystal.

(*b*) Crystal deformed plastically by shear stress parallel to hexagonal base, showing idealised picture of glide planes.

(*c*) Elastic deformation of crystal by shear strain normal to glide planes. In lake ice glide planes are parallel to the water surface.

arrangement of the water molecules this picture has to be enlarged approximately 1,000 million times. This has been done in Fig. 7, where the water molecules in the crystal are seen to be arranged in a regular pattern, and to be grouped together in layers which are parallel to the hexagonal base of the crystal. If a shearing stress is applied to such a crystal parallel to its base, the layers of molecules begin to slip over each other and, as a result, the entire crystal is deformed in the manner shown in Fig. 6b. This shearing of crystals parallel to definite planes is known as *gliding*, and the crystal planes involved are known as *glide planes*. Gliding is liable to occur in any crystals where the atoms or molecules are grouped together in layers. Since this is very frequently the case, particularly in metals, gliding is a property of great technical importance.

McConnel and Kidd's results on gliding in ice crystals were eagerly seized upon by several glaciologists and used as a foundation for improved theories of flow. Even so, the amount of knowledge available at the time as to the

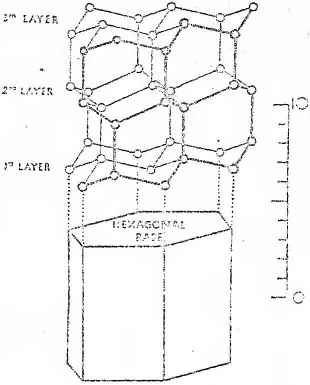

Fig. 7.—Crystal structure of ice. The lower part of the figure shows the outlines of a small ice crystal—in fact the smallest that could exist—and the upper part shows the arrangement of the water molecules within it. The molecules are represented as circles and the bonds between them as straight lines. To give the picture perspective the molecules facing the observer have been drawn in bold lines. The divisions of the scale are in Angstrom units, i.e., in 100-millionths of a centimetre.

plasticity of crystalline solids was insufficient for the formulation of a consistent theory. The inevitable contradictions and loopholes which these older theories entailed were partly responsible for the division of glaciological opinion into two rival schools of thought whose opposed and apparently irreconcilable views have dominated the glaciological literature until very recently. One school maintained that glacier ice is essentially plastic and that the differential movement observed in glaciers is effected through glide in individual crystals, accompanied by the growth of crystals

through the exchange of molecules across their boundaries. The other school fixed its attention—somewhat too exclusively—on certain systems of stratification bands which are commonly observed in glaciers and which they regarded as evidence for the existence of large-scale thrust planes. According to this school differential movement in the glacier proceeded through the spasmodic motion of rigid masses of ice over extensive thrust planes which take the form of cracks in the ice, and later, through regelation, develop into stratification bands.

The conflict between these two theories was finally resolved by the more powerful methods of observation and refined experimental techniques brought into the field by Seligman's Jungfraujoch Research Party in 1938.

RESULTS OF MODERN RESEARCH

The Jungfraujoch Research Party, of which I was fortunate to be a member, started its work with the immense advantage over all previous investigators of having its base at the International Research Station on the Jungfraujoch; being situated at the source of the Great Aletsch Glacier, this station offered ideal facilities for work on glaciological problems. Initially our programme was more concerned with the transition of snow into glacier ice than with the actual mechanism of flow.

Transition of Snow into Ice

The delicate lacework patterns of newly fallen snow crystals have always been the delight of nature observers and amateur microscopists, and have even served as a basis for mystical hypotheses on the geometry of the universe and the fundamental pattern of life. Plate 7 shows three particularly beautiful specimens among some thousands of snow flakes photographed in the course of a life-long study by W. A. Bentley of Jericho (Vermont).

A few days or weeks after it has fallen, snow presents an entirely different aspect. The fine needles, sharp corners

and plane faces, indeed all signs of regular and symmetrical growth, have disappeared and given way to rounded granules of considerably larger size, forming a loose conglomerate. A thin section of such aged snow is shown on Plate 8. For the first few years of their life in the firn region, these crystalline granules change little in size, but when the crystals finally emerge on the surface of the glacier tongue after having been buried for several decades or even centuries, they have grown to about a thousand times their original volume, have lost most of the air that was enclosed between them and have become firmly interlocked. (Plate 9).[5]

This metamorphosis of snow into glacier ice presented an interesting physical problem as such and was soon found to be closely related to the more general problem of glacier flow. In order to study this relationship more closely, we lowered ourselves into some of the deepest crevasses on the Jungfraufirn, cut samples of ice from their walls at different levels and examined these under the petrological microscope. The microscopic work was carried out in a laboratory which had been hewn out of the stationary ice on the Jungfraujoch and which kept a reasonable constant temperature of —4° C.

As a result of our research, and of subsequent experiments carried out by British, Swiss, and American workers, it has now become clear that the flow of glaciers and the growth of the crystals are analogous to similar phenomena in metals, with which scientists have long been familiar.

Creep

Differential flow in a glacier is due to the slow deformation of ice under the influence of sustained stresses. Such deformation is known in metallurgy as creep. Its physical mechanism is complex and can only be explained here in very general terms. Fundamentally, it is due to local re-arrangements of atoms in the crystals, leading either to the deformation of individual crystals by gliding or to the

transfer of atoms across their boundaries. The rearrangements of the atoms are activated by their thermal energy, i.e., the external force produces a deformation by giving a preferential direction to the otherwise random thermal movement of the atoms. A rise in temperature accelerates the creep rate by increasing the number of local rearrangements taking place at any given instant.

The creep properties of ice itself are still largely unexplored, but those of many metals are to a certain extent known, and can be applied to ice in a qualitative way. It will be useful first to describe some of the fundamental laws of creep and then to consider how they help us to understand the flow of ice in glaciers.

(1) If the temperature of an ice block is kept constant and the external force is varied, the creep rate will not vary as a linear but as an exponential function of the applied force. This means, for instance, that if an increase in the shear stress from 50 to 60 lb./sq. in. doubles the creep rate, an increase from 100 to 120 lb./sq. in. may quadruple it, an increase from 150 to 180 lb./sq. in. may multiply it eightfold, etc. In other words, the plasticity of ice increases rapidly with the applied stress.

(2) Below a certain stress, creep will not take place at all, and the deformation produced by an external force will be purely elastic. This minimum stress is known as the yield stress.

(3) At a given stress the creep rate of ice depends on the temperature. The closer the temperature approaches the melting point, the greater the creep rate. It was found in laboratory experiments, for instance, that at a certain stress the creep rate of ice at —1° C. is 1,000 times greater than at —20° C. This means that ice becomes increasingly rigid at lower temperatures.

Besides temperature and applied force, there are several other factors which influence the creep rate of ice, but none of these need be elaborated here, and we can now proceed to consider how the laws of creep which have just

been outlined could serve to explain the plasticity of ice in glaciers. First of all they show that no special mechanism —such as regelation—need be invoked to explain the existence of streaming motion in glaciers, since ice is only one among many other apparently brittle crystalline materials which can be deformed plastically by creep under suitable conditions. In addition, many of the more puzzling characteristics of glaciers can be understood in the light of the general rules set out above. Consider, for instance, the relation between creep rate and applied force. It has been mentioned that the large Greenland glaciers sometimes flow more than a hundred times faster than the smaller Alpine ones, although the difference in thickness may not amount to more than a factor of three or four. Such extraordinarily rapid flow is to be expected in view of the exponential relation between creep and applied force. It will be remembered also that in one instance an increase in the thickness of a glacier by only a quarter accelerated its flow by a factor of 16, thus giving rise to a rapid advance of the glacier-end. Obviously this is only another manifestation of the same mechanism. Seasonal variations in the flow velocity of the firn region where glaciers have recently been found to move twice as fast in winter as in summer are probably due to the same cause, the increased winter velocity being the reaction of the glacier to the weight of the newly deposited snow cover.

The existence of a yield stress below which creep does not occur explains the presence of crevasses as well as their limited depth. In theory, cracks in the ice might be produced at any depth, but no cracks in the interior of the glacier would be able to persist, since they would soon be closed by creep under the pressure of the overlying ice masses. As we approach the surface, however, a critical depth will be reached where this pressure becomes smaller than the yield stress of ice; above this critical depth cracks in the ice could persist indefinitely, while below it they would be closed through creep. In actual fact the limiting

depth of crevasses is not as sharply defined as this statement would suggest, since the rate of opening of a crevasse may often be faster than the rate at which creep tends to close it in its lower reaches, so that for a time, at least, the real depth may be considerably in excess of the critical depth as determined by the yield stress.

The last of the three laws mentioned above related to the influence which temperature exercised on the creep rate. This is comparatively unimportant so far as Alpine glaciers are concerned, because practically their entire mass is always at the melting point of ice. In polar glaciers, on the other hand, temperatures vary at different depths, and the increasing rigidity of ice at temperatures below the melting point profoundly affects their behaviour. This point will be discussed in greater detail in the section on ice caps.

Annealing and Crystal Growth

In metals the heating or *annealing*, as it is called, of a cold-worked specimen is accompanied by an increase in the average crystal size, due to the growth of some crystals at the expense of others. Conditions prevailing in a streaming glacier are analogous to those in a metal undergoing deformation above its annealing temperature. This may account for the very large increase in the average crystal volume which accompanies glacier flow. Plate 10 illustrate this analogy by showing a strip of aluminium in which extension and subsequent annealing produced a striking increase in crystal size, and sections through a block of ice in which a more moderate but still very marked crystal growth resulted from plastic deformation by shearing.

What determines the growth of one crystal at the expense of another? In order to understand this process, we have to consider the thermal motion of the water molecules at the boundary between two ice crystals. At temperatures near the melting point there will be a continuous and rapid exchange of molecules between the two crystals; if both crystals are at the same temperature and free from strain,

the number of molecules migrating from crystal A to crystal B will be the same, over a period of time, as the number migrating from B to A, so that the volume of each crystal will remain unchanged. This state of equilibrium can be upset by making the energy content of the two crystals unequal. For instance, if the temperature of crystal A is raised relative to that of B; more molecules will migrate from A to B than in the opposite direction, with the result that B will grow at A's expense. Another way of raising the energy content of a crystal is to strain it elastically. Therefore, the effect of straining A more than B will be exactly the same as that of making A warmer than B, i.e., it will lead to the growth of B at the expense of A.

In a glacier, therefore, an increase in the average crystal size is likely to arise as a result of variations in the energy content of neighbouring crystals. This could be brought about in different ways, of which the simplest is probably this: Suppose two crystals A and B are in contact and are both subjected to the same shear stress, but the orientation of crystal B is such that its glide planes are parallel to the direction of stress, while those of A are normal to the direction of stress (see Fig. 6b and c). In that case B will be free to yield to the stress by gliding while A will undergo elastic strain. Thus A will have a greater energy content than B; this will lead to the growth of B at A's expense and eventually to the complete disappearance of A.

The example just given can be generalised in the statement that different orientation of crystals relative to the external stress leads to the growth of some crystals at the expense of others. This is due to the anisotropic character of the crystals themselves, i.e., the dependence of their mechanical properties on the direction in which an external stress is applied.

Present Views on Glacier Motion

We have seen in the foregoing pages how each advance in our knowledge of the fundamental properties of solid

matter has led in turn to a clearer understanding of the nature of glacier flow. To-day the "fluidity" of ice which used to mystify the early observers is seen as a natural consequence of the creep of ice under the influence of sustained stresses, and creep itself is known to be the outward effect of a multitude of atomic rearrangements which are activated by thermal motion. The stresses set up in the individual ice crystals during creep give rise to small differences in their energy content which are now recognized as the ultimate cause of the striking growth in the average crystal size during flow (Plates 11, 12).

The motion of rigid masses of ice over large-scale thrust planes to which some observers had attached such exclusive importance exists, but may be regarded as a subsidiary rather than a primary factor in the mechanism of flow. It does not necessarily take place along actual cracks in the ice, but preferably along bands of large crystals which are oriented with their glide plane parallel to the planes of shear.

Temperature Distribution in a Glacier

It has long been known that Alpine glaciers are at the melting point of ice, except for an insignificant surface crust which is affected by external temperature variations. This may seem puzzling, because the mean annual temperature in the upper regions of Alpine glaciers is usually far *below* 0° C., and also because a glacier at or near 0° C. might be expected to melt away under the influence of the heat of the earth.

The clue to the thermal behaviour of glaciers is to be found in the very large difference between the specific and the latent heats of ice (0.5 as against 82 calories); so great is this difference that the heat liberated on freezing 1 gramme of water (the latent heat) is sufficient to raise the temperature of 160 grammes of ice by 1° C. Or, looking at it in another way, very little heat is needed to raise the temperature of an ice block from —1° to 0° C., as compared

to the heat required to turn the same ice block at 0° C. into water at 0° C.

Consider the firn region of a glacier at the end of September when its entire mass is known to be at the melting point. At the onset of winter a new layer of snow will be deposited and at the same time a wave of cold temperature will slowly sink into the glacier. The thermal conductivity of the new snow layer and of the layers of snow deposited in previous years is so poor that the winter cold wave does not penetrate further than about 50 feet below the surface. In spring the snow at the surface begins to melt, and the meltwater trickles down through the porous snow, re-freezing on reaching the colder layers below. The heat which the meltwater liberates on re-freezing is sufficient to bring all the snow back to the melting point and thus to wipe out the entire effects of the winter cold wave before the end of June. This is what happens in the firn region. In the glacier tongue the winter cold wave travels less far, on account of the higher temperatures prevailing in the valleys, and in spring its effects are very soon obliterated by the heat of the sun which penetrates sufficiently deeply into the clear blue ice to warm it up to melting point.

It can be shown on theoretical grounds that, even if surface melting were entirely absent, the flow of heat from the interior of the earth would warm up most of the glacier to the melting point, owing to the relatively small specific heat of ice. The latent heat of ice, on the other hand, is so great, that the heat of the earth does not melt more than a layer half an inch thick from the bottom of a glacier in a whole year.[6]

It should perhaps be pointed out that although the bulk of the glacier is at the melting point of ice, this does not imply that it is exactly at 0° C. It will be remembered that the melting point of ice is reduced by 0.0075° C. for every atmosphere of hydrostatic pressure. Ice in the interior of a glacier will, of course, be under a pressure corresponding

to the weight of the overlying ice masses. The consequent rise of pressure with increasing depth below the glacier surface should therefore be accompanied by a temperature gradient amounting to —0.21° C. for every 1,000 feet of ice. This is a fact which has long been verified by direct measurements.

ICE CAPS

Glaciers can be divided into two broad classes: ice streams and ice caps. So far this article has been concerned with the properties of ice streams, since they are of more general interest to the traveller and mountaineer. Yet from the point of view of their total mass, the ice caps are the more important by far, since they occupy at least five out of the six million square miles of glaciated territory on the earth. Ice caps are broad cake-like masses covering plains and mountain plateaux in polar regions. The largest are the ice caps of the Antarctic continent and of Greenland, the latter reaching a thickness of over 6,000 feet. Among the smaller ice caps, the Vatnajökul in Iceland and the Jostedalsbrae in Norway are the best known.

Some of the most interesting glaciological work has been done on the Greenland ice cap, whose vast expanse of flat country, unsheltered from the wind and exposed to appalling temperatures, has not deterred expeditions from spending the winter there. One of the most fruitful of these was a German expedition under Wegener who established a research station at the centre of the 450 mile wide plateau and wintered there in a large—and exceedingly cold—dugout. Wegener and his colleagues were the first to determine the depth of the ice cap; they did this with the help of seismic soundings, a most useful geophysical method which consists in the seismographic recording of the echoes from an explosion set off on the ground. The depth can be calculated from the time interval which elapses between the explosion and the receipt of its echo from the rock-bed under the glacier.

One of the most important findings of the Wegener expeditions concerned the economy of the ice cap. Their problem was to decide whether the ice cap is largely a stagnant mass of dead ice, built up in some previous age when snow falls were more abundant than they are now, or whether the ice cap is being nourished by regular falls of new snow even to-day. Sorge, one of the members of the expedition, dug a deep shaft in order to measure the thickness of successive layers of annual snow accumulation and found this to amount to an average of 34 inches of snow, corresponding to a height of over 12 inches of water.

Sorge's data at first sight seemed to suggest that the ice cap is continuously getting thicker, which is hard to believe. An alternative explanation offers itself if the ice cap is regarded as a vast mass of plastic material sagging under its own weight. The precise mode of sagging will be determined by the creep properties of ice, i.e., by its rate of creep at a given load and temperature, which have yet to be measured. The general type of behaviour, however, can be predicted from the laws of creep which have just been explained: the increase of plasticity with rising load, its decrease at negative temperatures and the existence of a yield stress.

The temperature in the Greenland ice cap rises from —30°C. at the surface to the melting point some thousands of feet below. Hence we should expect the ice cap to be comparatively rigid in its upper layers and to become increasingly plastic at greater depths, since the creep rate is likely to rise with depth both as a result of the increasing weight of the overlying layers of ice and of the rising temperature. These considerations led to the prediction that the sagging movement of the ice cap is likely to produce internal currents of ice flowing from the centre towards the margins of the ice cap. The currents should be fastest in the neighbourhood of the rockbed and slow down gradually with increasing height; their velocity probably becomes negligibly small as soon as temperatures below the melting point are reached.

This picture of internal ice currents not only provides the clue to the economy of the Greenland ice cap, but also explains the origin of the vast ice streams which flow through the marginal mountain ranges of Greenland and terminate in the sea. An ice cap in equilibrium is seen as a gigantic cake of plastic material which loses as much height in each year by sagging as it gains by the deposition of new snow. The sagging movement leads to the extrusion from the interior of vast quantities of ice which in at least one locality reach the sea in the form of a solid sheet many miles wide; mostly the extruded ice descends from the high central plateau to the sea in the form of valley glaciers. The annual snow accumulation on the ice cap has been estimated to amount to an equivalent of 270 cubic miles of water, of which about half reaches the sea in the form of ice-bergs and the remainder as melt water.

GLACIERS AND CLIMATE

The advances and recessions of glaciers throughout the ages bear an interesting testimony to the variations of climate which have occurred during the, geologically speaking, recent past. It is well known that at the time of the Great Ice Age which ended approximately 10,000 years ago, many now fertile regions of land were covered with glaciers and that the climate of most of the earth at that time was more severe than it is to-day. Since the recession of the Ice Age, there have been several major changes in glaciation which may have had considerable influence upon human history.

There is reason to believe that the Ice Age was followed in the temperate zone by a period of climatic optimum when glaciers were much smaller than to-day and that a new period of more extensive glaciation set in about 4,000 years ago, lasting until the present time. Apart from these large-scale variations there have been several minor ones in the historical past among which the advances which took place in the course of the 17th, 18th and 19th century are the ones

which are most easily ascertainable, partly with the help of old documents and drawings and partly from the evidence of moraines. The most recent advances took place towards 1750, 1820, 1850, and from about 1885 to 1895. Since then glaciers all over the world have gone through a period of recession which has assumed an increasingly rapid pace since 1930. No accurate measurements are needed to observe this recession. It can be seen by anyone visiting some of the hotels which were built in Switzerland towards the end of the last century for the purpose of offering the traveller a comfortable close-up view of those supposedly inaccessible wastes of ice. In many of these places the glacier has now disappeared from view, so that the names of the establishments (Hotel Gletscherblick, etc.) appear as much out of keeping with the times as their Victorian architecture. More serious than the fading attractions of these tourist resorts is the reduction in water supplies for hydro-electric power which the glacier recession threatens to bring about.

The recession of glaciers in the Alps is part of a worldwide phenomenon which is manifesting itself in a variety of ways. In the Northern hemisphere glaciers in Greenland, Spitsbergen, Iceland, and Scandinavia have all been affected; those in Southern Norway are thinning so fast that their complete disappearance seems not improbable. At the same time the border of the Arctic pack-ice is receding northwards, so that the coal shipping season in Spitsbergen, for instance, now lasts for 230 days out of the year, as compared with an average of 95 days in 1909-12. In Northern Russia the line of permanently frozen ground has receded in some places by as much as 25 miles, thereby opening up large new areas to cultivation. A marked retreat of the pack ice has also been reported from Antarctica.

What are the causes of glacier variations? They may be due to changes either in atmospheric temperature or in the total impact of radiation (which is partly associated with the intensity and variation of sunshine) or in the annual precipitation of snow. The Swedish glaciologist Ahlmann and

his colleagues have recently made a thorough study of this problem and concluded that changes in temperature and in the general vigour of wind circulation are the dominant factors influencing glacier size [7]. The present glacial recession, therefore, seems to indicate that the climate of the earth is getting warmer. This is in accord with other evidence such as, for instance, the steady rise in the mean annual temperature which has been recorded at Stockholm for the past 180 years. The rise only amounts to about 1°C., which may seem very little, but is in fact large enough to have spectacular effects on vegetation and glacier size.

It is hardly surprising that the analysis of glacial variations which have occurred in the past should have aroused a desire to predict future variations, a desire which has led to a certain amount of speculation on the existence of regular glacial cycles. Thus Bruckner, on the basis of the variation of general climatic phenomena recorded in historical documents, proposed a theory of climatic cycles with a 35-year period in which glaciers were also included. Others believed changes in glacier size to be associated with the 11-year cycle of sunspot activity. Recently more careful analysis of all the available data has done much to dispel people's belief in the existence of regular climatic or glacial cycles and has convinced many that records of climatic changes in the past offer no guide to the prediction of such changes in the future.

In connection with some of the more modern hypotheses on glacial cycles it may not be inappropriate to quote de Saussure's comment on the belief once held by the peasants of Chamonix that the glaciers descending from the Mont Blanc advance and retreat at regular intervals of seven years: "L'existence des périodes est un fait certain, leur régularité seule est imaginaire; comme on le sait, la régularité plaît aux hommes, elle semble leur assujetir les événements; et ce nombre mystérieux de deux fois sept années, assez grand pour que le souvenir de l'état précis des choses se soit effacé de la mémoire de ces bons gens qui ne

tiennent aucun registre, a pu facilement trouver créance dans leurs esprits."[1]

Conclusion

Glaciers may be shrinking, but interest in them is still expanding, as shown, for instance, by the recent formation of a British Glaciological Society. The execution of glaciological research has been helped by recent governmental and political interest in the polar regions, but the impetus behind this renewed activity is still due to the purely academic interest which the intricate problems of glacier flow have for the physicist and geomorphologist. Although most glacial phenomena can now be explained in a qualitative way, we still lack a precise correlation between the plastic properties of ice and its behaviour as a mass, and much research will be needed before it will be possible, for instance, to predict the flow properties of a glacier from the dimensions and inclinations of its bed or to account for many of the facts of glacial erosion. Some of the research now being initiated in this country and elsewhere may help to elucidate these problems.

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Physics Front

BY A. W. HASLETT

Atomic Energy Comparisons

BRITAIN'S first atomic pile is now in operation at the Ministry of Supply's Harwell Research Establishment, under Dr. J. D. Cockcroft. Its official title of the "Gleep," standing for Graphite Low Energy Experimental Pile, may sound unimpressive in relation to the information which has lately been published on the progress made by German physicists during the war years towards the release of atomic energy. The fact is that most of the basic knowledge which was needed was already available before the outbreak of war; and that apart from preliminary investigation, the entire Anglo-American effort in applied research was concentrated on the American side of the Atlantic. Hence the contrast in dates – which, however, is salutary as an indication that there is no mystery about the main facts of atomic energy. Prof. Heisenberg, whose name was internationally familiar before the war, and who was in immediate charge of Germany's atomic energy project, has given an interesting account of what was planned and achieved; which, for reasons unknown, has been allowed to appear in print in advance of the official United Nations' report on the subject, the existence of which has already been made known. Compared with Britain and the United States, it appears that progress up to the year 1942 was closely similar. Even by 1939, German physicists were already feeling their way towards the design of a nuclear pile, in which energy would be continuously released; it was recognised that the energy from the fission of Uranium-235 could be made available, in theory, either as a source of power or in the form of a bomb; and for the latter

purpose, it appeared in Germany as in the United States that the necessary first step would be the laborious and expensive separation of Uranium-235 from the more common form Uranium-238 with which it is normally mixed. From that stage on, a mixture of motives appears to have operated. Prof. Thirring of Vienna, an open anti-Nazi who lost his university post on that account, has stated that the best of Germany's physicists had felt that it would be a "crime" to provide Hitler with an atom bomb. Prof. Heisenberg writes more cautiously of the wish of the scientists concerned to keep developments in their own hands, and their prejudice in favour of the power application. In any case, as he admits, the final decision was removed from them by the hard facts that the Nazi leaders would permit no research effort which did not promise early application, and that in a Germany which was at war and beginning to feel the weight of an air offensive, the scale of effort applied in the United States would not have been possible. There were discussions with the naval authorities on the possible application of atomic energy for the propulsion of naval vessels—which would have been able to remain at sea for long periods without refuelling—and only limited research on the scientific side. None the less the position at the end of the war was that a small nuclear pile had been completed, which would have functioned in all probability as a self-sustained source of power, if only a relatively small amount of pure uranium metal had been available. Incidentally, there seems to have been no difference in principle between this pile and those designed in the United States, so that the assumption made by many of the more vociferous in that country that no one else knew anything about atomic energy is patently proved absurd. It is also of interest, in connection with this German approach, that one of America's leading electrical engineers has lately expressed the opinion that the propulsion of large ocean-going vessels, merchant as well as naval, may well provide the first "genuinely commercial" application

of atomic energy. He agrees, however, that the use of atomic energy on land, as a supplement to other sources of power, will come more quickly in countries where fuel is either expensive or in short supply. Britain can certainly fulfil the second of these requirements.

See Heisenberg, *Nature*, 1947, pp. 160, 211; Winne, *Electrical Eng.*, 1947, pp. 66, 631.

Radioactive Catalogue

Apart from various nuclear investigations which will be of value in the final design of the larger nuclear pile at Harwell, which is expected to be ready some time in 1948, the existing "Gleep" will be used in the interval to supply small quantities of artificially radioactive materials for research use. It has been stated by Dr. Cockcroft that Harwell proposes to make and supply all radioactive forms which have already been listed as "on the market" in the United States; and in addition to offer what can best be described as a "consumer demand" service. The order of priority will be Harwell's own requirements first; university laboratories next; and other research laboratories, including those of industry, third. Such, at least, will be the general policy. In detail, allocations will be administered by a committee, which will be in a position to treat individual cases on their merits, and on which the Medical Research Council, among other bodies, will be represented. Ability to take adequate safety precautions is likely to be made an absolute requirement. One suggestion is that joint local committees should be set up to settle the possibly invidious question of what laboratories are, and are not, equipped to handle radioactive substances. Detailed standards have also been worked out at Harwell to ensure safety in transit. Photographic film will be used to give a final overall check of the amount of radiation which is penetrating the protective lead casing; and there will be a limitation on the number of "cans" that may travel together.

We Are All Radioactive

Examples continue to multiply of research uses—mainly, as might be expected, from the United States, where the supply position is relatively good. One of the most intriguing is due to a research team led by Prof. W. F. Libby of the University of Chicago. He has found that all living things are in a very small degree radioactive. The argument which led him to this particular piece of research began from a quite natural speculation—to one versed in atomic energy—as what the effects on the atmosphere might be of the neutrons which cascade through it as a part of cosmic radiation from outer space. Even before the war, it was known from the work of Prof. Enrico Fermi (whose name is now associated with the design of the nuclear pile) that neutrons were an extremely effective agent in bringing out atomic transmutations. And, after the demonstration of this fact given on an engineering scale, first in the nuclear pile, and later in the atom bomb, it was natural to consider what changes the atoms of the air might be expected to undergo from the similar, but less intense, treatment to which they are continually exposed. Prof. Libby concluded from the known results of laboratory experiments, that the most likely change was the conversion of atmospheric nitrogen into radioactive carbon. As the average life of a radio-carbon atom is some seven thousand years, he saw further that this radio-carbon would have plenty of time in which to be absorbed from the air by plants in the form of carbon dioxide; built up by plants into sugars and proteins; eaten by animals and incorporated into their own bodies; and either be breathed out again into the air as carbon dioxide, or else find its way into the sea or soil. From such data as were available, he predicted that all carbon derived from living forms—or equally from the air, sea or soil—would be found to be radioactive to the extent of between 1 and 10 disintegrations per gram weight per minute. This is a fantastically small amount of radioactivity to seek to demonstrate...

trating the radio-carbon obtained, in the form of methane, from the Baltimore City sewage works, Prof. Libby has been able to confirm that the predicted radioactivity of organic carbon is a real phenomenon. As a check, he attempted to apply the same process to other samples of methane from petroleum, which has been long enough below ground to have lost any radioactivity it may once have possessed; but in this case no amount of concentration produced any measurable effect. It looks, therefore, as if we are all, as Prof. Libby predicted, a little radioactive, and that this radioactivity is derived in the first instance from whatever cataclysms in stars or space give rise to cosmic radiation. It is a majestic conception, which it is something of a technical triumph to have been able to confirm; and, if Prof. Libby's work does nothing else but draw attention in dramatic form to the reality of the "carbon cycle" on which all life ultimately depends, it will probably have been worth while. But it has no bearing whatever on, for example, the *practical* problems of plant nutrition. Plants get the carbon they need from the air.

See Libby, *Phys. Rev.*, 1946, pp. 69, 671; Anderson, Libby, Weinhouse, *et al.*, *Science*, 1947, pp. 105, 576.

Research Uses

Other and more practical uses of radio-activity in physics and industry have been discussed at a conference held by the Institute of Physics, against the day when Dr. Cockcroft will be able to make supplies more readily available. The method is the same, in principle, as that used in the United States studies of blood storage and transfusion which were mentioned in *Science News* 2. The point in each case is that radioactive atoms take part in the same chemical and physical changes as do normal stable atoms of the same chemical element; but, because of their radioactivity, can be followed, with no room for argument, wherever they may go. In one engineering application, mechanical wear has been studied in moving machinery by incorporating

suitable radio-elements in test alloys, and then looking for whatever radioactivity may have been imparted to the lubricating oil along with the usual metallic dust. In another, the radio-element used as a "tracer" has been employed to measure the efficiency with which smoke filters were preventing the passage of fine dust. Still another application has been in the study of flow patterns in the ducts carrying furnace gases. Tackled by normal methods, this would involve measurements of the rate of diffusion of gases under turbulent conditions, which cannot easily be carried out, although it is clearly of practical value to the designer to know the form which the flow patterns take under different conditions. Finally, and as an example of quite a different kind of use, it has been found useful as a fire precaution to incorporate small amounts of radio-active material in the running belts of grain elevators. The point, in this case, is that a mixture of grain particles and air can form an almost explosive mixture, so that any sparking due to the electrical charge built up by friction on the running belts could be dangerous. The effect of the radio-activity is to ensure that any electric charge on the belts leaks away smoothly and continuously, without ever reaching the danger level. The possibilities offered by these new radio-active materials in "pure" research are undoubtedly more important; but these practical and engineering examples give, somehow, a reassuring impression of reality.

See Institute of Physics Conference on Applications of Radioactive Tracer Research and Industry, 1947. *J. of Scientific Instr.*, in the press.

Alloy Research

Apart from obvious and immediate efforts to produce new alloys capable of withstanding, for example, the impact of hot and high-speed combustion gases in a gas turbine, without either corrosion or loss of rigidity, there has been a good deal of alloy research lately of a more fundamental kind. And it may be worth emphasising that it is from such

work, rather than from the use of trial-and-error methods, however successful, that the biggest advances must in the long run be expected. One such research, carried out by Dr. A. Guinier in Paris, has had as its object the explanation of the accepted process of "precipitation hardening," in which a "keying" effect is brought about by the precipitation, through sudden cooling, of small crystals of one metal from solid solution in another. What probably happens is that these minute "keys" act as so many check-points on the "slipping" which would normally take place within larger crystals. This picture is supported, among other work, by Prof. Andrade's demonstration that wires made of single crystals of almost perfectly pure metals are among the weakest of solid materials. Dr. Guinier's achievement has been to measure, by X-ray methods, the shape and distribution of these keying nuclei in two comparatively simple cases. Working with aluminium, which has a cubic structure, to which 4 per cent of copper had been added, he found that the latter deposited itself in flat disc-shaped nuclei, arranged parallel to one or other of the three planes of the crystal cubes. The average spacing between nuclei was of the order of a hundredth of a wavelength of light, the nuclei themselves being even more submicroscopic. If zinc was used instead of copper as the added metal, the spacing was of the same order, but the nuclei were now spherical instead of disc-shaped. Other experiments of Dr. Guinier's have confirmed, so far as they go, the belief that the size of these invisible keying nuclei is connected with temperature. The more sudden the cooling, and the lower the temperature at which precipitation takes place, the smaller are the nuclei. As regards stability, merely transient changes in temperature should bring no change. But if such an alloy is left for a long period at a higher temperature, then there will be partial re-solution, with re-precipitation in the larger particle sizes characteristic of the higher temperature. This means that if the original particle size was correctly chosen

for maximum hardness, prolonged heating will lead to a loss of hardness, even although the temperature reached may have been well below the melting point of the alloy.

This has provided the starting point for a new type of alloy which has been made experimentally by Dr. J. L. Meyering of Eindhoven, Holland. His argument was that if he could arrange that his keying nuclei were composed, not of the alloying metal itself, but of a stable oxide, then no amount of later heating would cause the nuclei to re-dissolve. The original particle size would thus be retained, and there would be no loss of hardness from heating. His procedure was to take a small amount of a metal which combines readily with oxygen—for example magnesium or beryllium—and a larger amount of metal which does not; prepare a solid solution of the first in the second; and heat this in an atmosphere of oxygen at a temperature one or two hundred degrees Centigrade below the melting point. Under these conditions the oxygen penetrates the solid metal and combines chemically with the favoured metal. With silver as the main metal, and between $\frac{1}{2}$ and $1\frac{1}{2}$ (by atoms) of magnesium or beryllium, an increase of about five-fold in hardness was obtained. With copper or nickel as the main metal, the relative gain was about half as great. For other reasons—of which brittleness is one—none of the few test alloys which he has so far produced appear practical. It is also a restriction on the method that the "main metal" should not itself be readily oxidised. On the other hand, the general principle that the "keys" of precipitation hardening can be "fixed" by chemical combination against the effects of temperature changes should be capable, in some shape or form, of practical use.

See Conference on the Strength of Solids, University of Bristol and Institute of Physics, 1947, in the press.

Daylight Meteors

One very striking result of the use of radar methods to record the arrival of meteors in the upper atmosphere has

been the discovery of a hitherto completely unknown stream of meteors at the Jodrell Bank Experimental Station of the University of Manchester. This is under the immediate direction of Dr. A. C. B. Lovell, who was one of our radar scientists during the war, but forms part of the physics department of which Prof. P. M. S. Blackett is the head. There are several unusual points about these meteors. The first and most striking is that they are a "daylight stream," which from the nature of the case could not have been detected by the normal method of visual observation. This division into night streams and daylight streams arises from the fact that, whereas the earth's orbit round the sun is not very far from circular, the orbits of meteors are for the most part highly eccentric, passing very much closer to the sun than we do at one point, and at the opposite extreme travelling out into more distant regions of the solar system. Ignoring complications, this means that the meteors of any particular stream may approach the earth from either of two different directions. They may be detected, as in the normal cases, when they are moving in towards the sun, and so approach the earth on the side which is in darkness; or, as has now been made possible by radar, they can be picked up when they are moving out from a point near the sun, and so reach the earth on the "daylight side." There is therefore a special interest in the detection for the first time of a stream of this kind. It is something which could not before have been done. The second interest of these new meteors is that the stream of which they form part appears to be unusually widely spread. As an example of what normally happens, the Geminid meteors of December gave, in 1946, a radar count of twenty or more meteors an hour on only four days, and the peak count for the whole display was only 43 an hour. In other words, we had passed through the most heavily "populated" part of the meteor stream in the course of about four days, during which the earth would have travelled rather more than three million miles in its

orbit round the sun. The new meteors, on the other hand, although first observed in May, were still going strong in July; and for about two months the maximum daily count rate never fell below the figure of twenty meteors an hour which has already been quoted in the case of the Geminids. This implies a spreading out of the meteor stream to an extent which has never before been observed, and will give the astronomers who are now at work on the results some quite difficult problems in interpretation. The usual, but unproved, assumption is that each of the main meteor streams which the earth encounters is associated with some particular comet. The basis for this belief is that they appear to follow closely similar orbits; and the fact that the comet itself is only seen once in each revolution round the sun, whereas the meteors are seen annually, is explained by supposing that the latter have become spread out lengthwise round the entire orbit which they follow, as sometimes happens with athletes in a long-distance race. Knowledge of this kind of spreading out is dependent, naturally, on looking for the same meteor stream year after year, and finding that some of its representatives always turn up. The spreading out which has been observed in the new meteor stream is, as it were, sideways. It is as if the track itself had been broadened out—and that to the extent of about one hundred million miles, or more than one-sixth of the earth's total orbit round the sun. For this reason, there is some doubt as to whether the whole of the new meteors can be associated with a single comet. A possible alternative is that the orbits of two or more different meteor streams may pass close together, giving the impression where they cross the earth's path of a single stream. If all the meteors "belong" to a single comet, it is probably Halley's, the most famous of them all.

See British Astr. Ass. Circular, 1947, No. 282.

The Aurora Borealis

The Aurora Borealis, long admired by visitors to northern

latitudes as one of the most impressive of natural spectacles, is also one of the best available methods of studying the upper atmosphere. Physicists, incidentally, prefer the description Aurora Polaris, since Borealis means northern, and these displays of luminous arcs, bands and curtains are as characteristic of southern polar regions as of the north. In either case they are believed to be due to the impact of electrically charged particles on the earth's atmosphere—the effect of the earth's magnetism being to guide these particles towards either the north or south magnetic poles.

To the meteorologist, in the long run in relation to weather forecasting, the chief claim of the Aurora to interest is that it affords the one means available—short of high altitude rockets—of studying the whole range of the earth's atmosphere from about 60 to about 600 miles above the earth. Several different lines of approach are possible. The oldest, due to Professor Störmer of Oslo, is the systematic collection of the heights of Auroral displays, by simultaneous photography from two or more stations. From his network of stations in southern Norway, he has now some 12,330 measurements of height at his disposal, and he reckons that a further 8,000 heights can be secured from existing photographs. He has, therefore, published a first analysis of all these observations, and is now setting systematically to work to secure the greatest possible information from the large mass of photographs already taken.

A second approach, in which the French school of physicists has long specialised, is the detailed study of the radiation produced not only by the Aurora itself but also, although at very much less intensity, by the normal night sky. This has shown that the chief components of the upper air are oxygen in the atomic state, nitrogen as at ground level, and possibly some few other elements, including sodium believed to be derived from meteors. Much work of this kind was discussed at an international conference

which was held lately in London by the meteorological research committee of the Royal Society.

Still more lately, Dr. A. C. B. Lovell, of the University of Manchester (whose work on meteors was mentioned in the preceding paragraph) has found that radar methods can also be applied to the Aurora. At the Jodrell Bank Experimental station near Manchester, he has obtained radar echoes during last summer from a luminous cloud at the tip of one of the well-known Auroral streamers. He was able, in addition, to measure the electrical state of the cloud, and to compare this with that of "normal" air at the same time and height. He found that the number of free electrons in the cloud was roughly one hundred times as great. Although clearly of more use to Professor Störmer in Norway than in England, it would seem therefore that a valuable new method of studying the Aurora has been discovered.

See Störmer, *Terrestrial Magnetism*, 1946, pp. 51, 501; Lovell, Clegg and Ellyett, *Nature*, 1947, p. 160, 372.

New Law of Magnetism

The magnetism shown by the earth, and as soon as it could be measured by the sun also, has long presented a problem to physicists and astronomers. The fact that the line joining the north and south magnetic poles of the earth is in roughly the same direction as the line joining the two geographical poles carries an obvious hint that the earth's rotation may have something to do with its magnetism. And, as long ago as 1891, it was suggested that it might be the cause of it. At this time, there was no other large and rotating body with which comparison could be made; and there was also the quite formidable difficulty that the earth's magnetic axis was in a direction ten degrees different from its axis of rotation. This meant that even if the rotation of the earth was a main cause of its magnetism, it would still be necessary to provide a second theory which would explain the discrepancy. Then, in 1910, the first

measurement was made of the magnetism of the sun. In this case, too, it was found that the magnetic axis corresponded nearly, but not quite, with the axis of rotation. The discrepancy was a little less, about four degrees instead of ten, but still large enough to require explanation. Thus the position remained until the beginning of the present year, when Dr. H. W. Babcock of Mount Wilson Observatory, California, published the results of the first measurements which have been made of the magnetism of a star. As it happened, Prof. Blackett of Manchester was already interested in the problem, since the earth's magnetism had affected his own work on cosmic radiation. Not all of the particles found in cosmic radiation are electrically charged. But the effect of the earth's magnetism on those particles which are electrically charged is to cause them to approach the earth along a spiral course, with the slower-moving particles making predominantly for one or other of the magnetic poles. The point, in the present connection, is that Prof. Blackett had already been used from his own work to thinking about the earth's magnetism; and being a physicist, he thought in general terms, rather than special and elaborate explanations based on speculation as to what might be going on within the earth's crust. With this approach, he was struck by the fact that, in the case of the earth and the sun, the "strength of magnetism" (magnetic moment) of these two bodies was proportional to their angular momentum—the latter expression meaning, in effect, the time for which a specified braking force would have to be applied, at the same distance from their centres, to bring them to rest. "Quantity of rotation" is another way of expressing the same quantity. It depends, in any case, on three factors—mass, rate of angular rotation, and degree of compactness; and is about ten million times greater in the case of the sun than in the case of the earth. Having got so far already, Prof. Blackett was naturally quick to test his ideas against Dr. Babcock's measurements of the magnetism of the star, 78 Virginis, as soon as these

were available. Compared with the sun, he found that both the magnetism and the angular momentum of this star were increased in about the same proportion, and by a factor of some hundreds. He has suggested therefore, as a new law of nature, that any massive and rotating body is automatically a magnet, in virtue of its rotation; and that these two quantities, magnetic moment and angular momentum, are always proportional to one another. This, if true, is a very remarkable conclusion. So far, it rests on three cases only. The further possibilities are: First, confirmation from other stars; and, second, which would be much more convincing and satisfactory, that by rotating a sufficiently large bronze sphere at a high enough rate, it might be possible to demonstrate the same effect in the laboratory. The indications are that the magnetism due to the rotation of such a sphere should be just, but only just, detectable. It should be added that some few weeks after Prof. Blackett's announcement in England, Dr. Babcock put forward similar ideas in the United States.

See Blackett, *Nature*, 1947, pp. 159, 658; Babcock, *Astrophys, I.*, 1947, p. 105.

The Heat Pump

Anything which can lead to a saving of coal is of obvious importance under present conditions both in Britain and in Europe as a whole. Also, and apart from any immediate shortage in supplies, it is clear that as wage standards and living conditions are improved, it becomes economic to spend more money on capital equipment which will lead to fuel economy. It is for these two reasons that engineers have lately been taking increased interest in a device which, although generally unfamiliar, has been recognised as a theoretical possiblity for more than a century. This is the "heat pump," no longer an idea, but a practical engineering device. It has been used by Mr. J. A. Sumner, City Electrical Engineer to the Corporation of Norwich, to heat his own headquarters building through two winters, and has given

quite a remarkable degree of fuel economy. This is the first practical test of such a system in Britain. It showed that, whereas with a coal-fired boiler some 55 per cent of the heat released by the fuel was wasted, with a heat-pump the amount of useful heat supplied to the building was actually slightly greater than the heat-value of the coal burnt at the power station from which power was obtained. This sounds impossible—and would be if all the heat supplied to the building had come ultimately from the coal. However, as the name "heat pump" suggests, its purpose is to pump heat from one place to another; and, in this case, the water of a neighbouring river was being cooled at the same time as the radiator water in the building was being warmed. In other words heat was being "pumped" from the river to the building.

That this should be possible is demonstrated daily by any refrigerator. The case is perhaps most obvious with the gas type. With this, there is an obvious chimney and grating at the top, and anyone sufficiently interested can verify by placing his hand over it, that, so far as the room is concerned, the refrigerator is acting in a small way as a source of heat. Energy is being supplied from outside, in the shape of the gas flame at the bottom; and this energy is being used to "pump" heat from the food in the refrigerator into the room. The difference is one of purpose. That of a refrigerator is to cool food, and it is so designed as to give the greatest possible cooling for the smallest possible supply of energy from outside. In the case of a heat pump, as used by Mr. Sumner, the main purpose is to supply heat to the building, and this therefore becomes the controlling factor in design. As to the possibilities, the saving in fuel has already been mentioned. The Norwich figures show also that, under comparable conditions, there should be saving in cost as well. On the other hand there is a restriction in the fact that, for any "pump" of Mr. Sumner's type, it is necessary to have available a suitable supply of running water, part of which can be tapped off and cooled. But, as

against this, heat pumps in which heat is extracted from the air, instead of from water, are also possible; and one such design has been tried, and has worked, in Switzerland. Last, there is the possibility of combining the "heat pump" with air conditioning, in such a way that the air supply to the building is heated in winter and cooled in summer, using the same plant to do both jobs. As with any form of new and specialised equipment, time will be needed to work out the best systems, and for the necessary plant to be put into regular production. But on the main point, that heat pumps are likely to be used in the future for the heating of many large buildings, there can be little doubt.

See Sumner, *Proc. Inst. Mech. Eng.*, in the press.

Sugar as a Raw Material

New uses for sugar in industry are likely to result from the work of the Colonial Products Research Council. This body was set up in 1942, as part of the plans of the then Government for the post-war development of British colonial territories, particularly in the tropics. Its headquarters are at the Imperial Institute, and its director is Dr. J. L. Simonsen. One of the Council's terms of reference is "to advise what colonial raw materials are likely to be of value to the manufacture of intermediate and other products required by industry" and "to initiate and supervise researches". Two such materials are clearly sugar and starch. Of these, sugar is both the simpler chemically, and also the more likely, in spite of present rationing, to be again suffering from over-production within comparatively few years. Since 1943, therefore, within a year of the Council's formation, a team has been working at Birmingham University, under Prof. Sir Norman Howarth and Dr. L. F. Wiggins, on the various chemicals which can be derived from sugar. One such is a substance known as levulinic acid which, in the form of its sodium salt, is stated to be excellent anti-freeze for use in car radiators. Other derivatives of cane sugar may find application in the

plastics industry. More to the point, it has been found that crude uncrystallised cane sugar can be used as the raw material. Also, since the processes involved are comparatively simple, it should be possible for manufacture to be carried out in the countries of origin.

Another of the Council's proposed activities is the establishment in Trinidad of the first research institution in the British Commonwealth solely devoted to microbiology—the study, that is, of moulds, bacteria and other primitive forms of life. It is a branch of science which jumped from neglected obscurity into sudden prominence with the development of penicillin; but in fact it has long been known that the flavour of, for example, tea, cocoa and tobacco is greatly affected by the action of microorganisms, not necessarily for the worse, while in other cases they are responsible for serious plant diseases. One such is the notorious Panama disease of bananas, which may well prove critical for the banana industry of the West Indies. A recent discovery, which may be hopeful, is that a primitive soil fungus, also first isolated in the West Indies, can destroy the organism which causes the disease. This is being jointly investigated by a team of chemists at the Imperial College of Science and Technology in London, and on the biological side by Dr. A. C. Thaysen who will be the first director of the Trinidad Institute.

See Simonsen, *The Advancement of Science*, 1947, pp. 4, 166.

SCIENCE NEWS

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Editorial

CURIOUSLY enough, although nobody talks of 1939-45 as the war which ended War, nobody is yet discussing the form the next armed conflict will take. The exciting and terrible power of the atom bomb seems to have hypnotised us into claiming that the next war will end civilisation, and therefore must not occur; and at the same time that we will defend our way of life against anyone who tries to thrust another way upon us. It may not be of Britain's choosing; it may not be about or against Germany; but sooner or later, such being the way of mankind, it is highly probable another war will break out and we shall all be involved. It seems worth while to face this future realistically, which diminishes the terror. What will it be like?

Bacteriological warfare, at present a top secret on all sides, is a weapon aimed at the whole population. It seems possible that it might be developed along two lines. One is the simple spreading of infectious disease, for instance, by dropping large numbers of plague-infected rats into a city to start an epidemic, or by spraying infantile paralysis virus into the air over a town in a special way to ensure its aerial persistence and consequent continued infectivity. Although it is true that perhaps only two persons in every hundred exposed would get the disease seriously, or even at all, yet in a city of 500,000 this means 10,000 cases, which are quite enough to swamp all normal medical services and result in the stoppage of all activity, and a cease-fire. The other mode of attack depends on the fact that some bacteria produce amazingly powerful poisons. The toxin of botulism, for instance, is deadly even in the merest traces. It would be possible to make it pure by the pound and distribute it in water supplies or by aerial sprays with devastating effect.

Clearly the reply to this kind of warfare rests with the medical services. They will develop ways of rendering poisons harmless and the air fit to breathe, and they will teach everybody the rudiments of nursing and the recognition of the infectious diseases.

As for the atom bomb, apart from its use as a surprise opening to a war, which could probably thus be prematurely terminated through the resulting panic, its fearsomeness may be over-rated. It produces three kinds of attack: the destructive shock wave (blast), fires (flash) and radiation sickness. The first two of these can be minimised by a proper system of dispersal, deep shelters, and the increased use of underground food stores and factories, as already worked to some extent in 1939-45. Radiation sickness, its prevention, its treatment, is again a problem for the medical services. In fact the next war will be *par excellence* a medical war. Its outcome will depend entirely on the progress of medical research and the training of the Civil Defence Services.

These are a few random speculations: every scientist has his own pet ideas of what to expect and how to deal with it. The actual progress of military research can obviously not be included in *Science News*, but it seems worth while to draw attention to the kind of planning and development that must be going on. It is no use putting one's head under the blankets, and in an issue devoted largely to the applied sciences (High-Speed Flight, Craftsmanship, the uses of Photography, Calculating Machines) it would be wrong not to include at least some reference to the most important applications of all—to the next War.

Measuring Craftsmanship

DR G. W. SCOTT BLAIR

IT all looked so easy – until I tried it myself! Under the potter's hands the mass of clay climbed up so gracefully and evenly until the bowl was formed. I knew, of course, that the clay must be plastic enough to hold together and not to crumble in its rapid deformations, yet firm enough to hold its height. I asked the potter how he could tell whether a new batch of clay had the right 'plasticity'. 'Well', he said, twisting a rod of moist clay round in his hands, 'you can see if it'll stand bending like this; but really, when you've been making pots for thirty years as I have, you'll know the feel of your clay all right.' 'But how do you teach the youngsters?' I asked. 'Well, I can't rightly say that I do teach them. They learn for themselves, there's no short cut to knowing your clay!'

I tried my friend the baker. He was just starting to knead up his dough. 'That's a better flour' he said; 'That'll take about 15 gallons a sack!' 'How do you tell how much water it'll take?' 'Well – when you've been on this job for as long as I have ...'

So I went to the cheese store – rows of shelves from floor to ceiling almost as far as the eye could reach – literally thousands of cheeses. 'I wish my thumb didn't tire so quickly!' said the grader, jabbing that organ into the top of one of the cheeses. 'Ah, that's a better body for you!' I gathered that this remark referred to some quality of the cheese and not to the fallible human instrument used to test it. The grader was an old man and I wondered how many years it had taken him to learn his very skilled trade.

Now I've been more than twenty years at my job – a research physicist. I hope perhaps that with the large card

index I've collected and the much less reliable filing system of my memory, I'm more use at the job than I was when I started as a youngster with no more mental and physical equipment than my hastily acquired examination knowledge and my set of students' text books.

But this is the point: – If I had measured the viscosity of an oil or the electrical resistance of a wire even in those days, I should have got the same result as my most learned professor; or, if I hadn't, he would easily have spotted some silly mistake in my measurement. It would have been unthinkable for him to have said to me: 'When you've been doing physical measurements for twenty years or so you'll get a different answer.'

How does the viscosity of an oil or the resistance of a wire differ from the plasticity of a clay or the body of a cheese?

It would not be true to say that these latter things can't be measured by instruments – to some extent they can; but, unlike viscosity and electrical resistance, the best we can hope from measurements of plasticity and body is that they shall not depend on the skill of the person who makes the test (once he has acquired the very simple technique needed to work the apparatus). The results will depend on the exact design of the machine and precise technique for its use; nor can we be perfectly sure that the 'plasticity' or 'body' that is measured will be exactly what the potter or the baker means by these terms.

Unfortunately, in most industries, the 'properties' of materials that are of practical importance are not simple physical properties like viscosity, or electrical resistance, but complex concepts like plasticity, of which Brogniart said, over a hundred years ago, 'On a souvent parlé de cette propriété, on semble la connaître, mais on n'en a qu'une vague idée'.

This being so, industry is bound to tend to rely on the skill of the old craftsman who knows his materials – nor is it always desirable to replace such craftsmen by machines. But there are many cases, especially in these times of econ-

omic difficulty, when the necessarily large scale of modern production makes it essential to control materials and processes by less subjective methods.

Cheese used to be made on the farm with a few gallons of milk at a time, and I am quite certain that no one will make anything as good as the best English farmhouse cheese, without craftsmanship, by means of clocks and machines. Yet it is positively pathetic to see an elderly and obviously harrassed cheese-maker trying to cope with a batch of 'slow starter' or an unexpected deterioration in milk quality in a big modern factory handling some 20,000 gallons of milk a day.

A director of an old-established firm said to me recently, 'We're prepared to use Science when it helps but not when it makes things worse'. I think that by 'Science' he meant 'Mechanisation' or 'Instrumentation', as the Americans call the mechanisation of testing materials. Science, as organised common experience properly applied, could hardly make things worse. But I sympathised with him, for I well remember on the continent some years before the war a country where the progress of vitally important wheat breeding experiments was controlled solely on the results from a dough quality testing machine, which I was able to show from figures already available on the spot, bore no relation whatever to the quality of the doughs as judged by experienced bakers and millers.

It therefore seems necessary to 'measure' craftsmanship in order to find out just what these 'properties' are which the potter, the baker or the cheese-maker claim to be able to assess by handling materials; to find out how small a change in such 'properties' the expert can correctly detect; by how much his judgments on any given material will differ on different occasions; how far the judgments of one expert differ from those of another; whether there is any quicker way of teaching this craft to apprentices; and whether when the hands serve as a testing machine, the expert uses his joints and muscles to their best advantage.

Often the expert does not himself know to what extent his judgments depend on sight or feel. Thus Binns found that a highly skilled wool-top tester could judge the softness of a wool no better than could a school-child when both were blindfolded, though the experts were certain that judgments were made by feel and not by sight. The baker, too, uses his eyes in judging the quality of doughs. Katz, following experiments on blindfolded bakers, reports that 'the baker, in judging doughs, is not absolutely lost without vision, but on the other hand, he can make the optical impressions the only ones to rely on if we want him to do so'. Katz himself kneaded the dough and asked the baker to judge its quality purely by sight.

Stickiness is an important factor in judging dough quality and must be taken into account in designing any instrument intended to measure 'body'. In the judging of stickiness, Katz found that temperature plays an unexpected part. 'The higher the temperature, the less sticky a dough will feel, the lower the temperature the greater the apparent (not the real) stickiness.'

Miss Sullivan has shown how misleading the feel of materials on the fingers can be if sight is excluded. A subject's finger was dipped into water at a series of different temperatures, the hand being screened so that the nature of the liquid could not be seen. As the temperature rose from the freezing point to 42°C., the feel was described progressively as (1) mushy – like partly-melted snow; (2) muddy – like mercury; (3) gelatinous – like gelatine; (4) wet – like water; (5) (at blood heat) oily – like oil; (6) greasy – like melted butter.

V. G. W. Harrison, in his interesting book on *The Definition and Measurement of Gloss** tells of the very complex blending of factors by which the gloss of paper is judged. 'Gloss meters' of all kinds have been made by the physicist, but Harrison says 'To sum up: for metals, paints

* Printing and Allied Trades Research Association, London, December 1945.

and varnishes, the "objective" gloss meter may be satisfactory for certain purposes; for textiles and papers, no'.

In our work at the National Institute for Research in Dairying, we have found that expert cheese-makers tend to judge quality of cheese as a whole and that such judgments of quality are more reproducible than are those of non-experts. But the experts find it hard to judge one factor (say firmness) separately from another (such as springiness) and, as a result of this, the judgments of non-experts, though less self-consistent, often agree better than do those of the experts with testing instruments which measure isolated physical properties.

Plate 38 shows a cheese-maker testing the quality of cheese curd in the making. Plate 39 shows an instrument for measuring the weight and height (and hence the density) of a cylinder of curd on the principle that the softer the curd, the less easily can the heavier whey drain out of the test-cylinder to be replaced by lighter air. The results of the density test agree well with the expert's judgment.

Plate 40 shows a grader about to judge the firmness or body of a 'plug' taken with a special borer from the cheese. Plate 41 shows a hardness tester in which the penetration of a ball into the surface of the cheese under a standard load is measured. This serves as a kind of 'mechanical thumb' and agrees fairly well with the grader's opinions. Keestra, in Holland, has made a similar study of the firmness of butter as judged by 'thumbing'.

In order to determine the 'thresholds' or just noticeable differences (j.n.d.'s) when people compare the firmness of two materials by squeezing one in each hand, we started by making experiments on materials which are physically simpler than cheese. Firmness of cheese cannot be expressed by any one single 'physical property', but there are certain bitumens which, though of about the same firmness as cheese, have the property of flowing at a perfectly steady rate under constant pressure and, when pressure is varied, at a rate proportional to it, so that even at the smallest

pressures they will flow very slowly. This means that for these materials, the conception of firmness must depend simply* on the constant ratio of pressure to rate of flow, which is called viscosity. Viscosity can be measured in a variety of ways, all of which should give the same answer if the temperature doesn't change.

Though rubber is not perfectly elastic, as a first approximation it is true to say that just as bitumen flows twice as *fast* when you press twice as hard, so rubber deforms twice as *far* and stays put when the pressure is constant. For rubber, firmness therefore depends on the nearly constant ratio of pressure to amount of deformation, which is called an 'elastic modulus'. When people were asked to squeeze, one in each hand, small cylinders of bitumen and, on other occasions, small cylinders of rubber and to compare them for firmness, trying to exert a steady pressure on each occasion, it is not perhaps surprising that it was found that rubbers could be compared with one another with about three times as small a j.n.d. as that found for bitumens. The former could be compared statically, by comparing amounts of deformation; the latter were flowing all the time and had to be judged by rate of flow.

Skilled cheese-makers did not notice smaller differences than the rest of us, but younger and less educated people did rather better than older and better educated people. I remembered this when, on a recent visit to a pottery, I watched very young girls manipulating clay with great skill and was told how satisfactory many of them were.

The j.n.d.'s don't seem to depend on the sensitivity of the skin so much as on the frame of mind of the tester. Routine analysts, who are used to doing very careful work day by day without knowing the purpose of the tests, and who do not worry as to whether they are doing better than their neighbours, showed strikingly low j.n.d.'s. Expert handlers of materials – cheese-makers, bakers, etc. – are apt to be

* Certain precautions have to be taken to ensure that this is really true.

suspicious in tests of this kind – and suspicion has a devastating effect on the thresholds.

It might seem therefore that such experiments do not tell us much about the real skill of the craftsman. Nor do they unless we go further to study more complex situations.

What happens if you compare for firmness a bitumen in one hand with a rubber in the other? The physicist will tell you with horror that you can no more describe a viscosity as greater or less than an elastic modulus than you can call 20 seconds greater or less than 15 feet. This, in a sense, is true. Yet few people have any difficulty in comparing rubber and bitumen for firmness. The decision as to which is the firmer depends on the time allowed for the squeezing. If this is controlled by means of a metronome or similar device, it is found that the time of squeezing and the elastic modulus of the rubber are equally important in effecting the decision.

By what factor is the judgment made? In comparisons of rubber with rubber, the deciding factor is the distances through which the rubbers compress under the steady pressure exerted.* In comparing bitumen with bitumen, it is presumably the rates of flow which are compared. In comparing a rubber with a bitumen, the judgment can hardly depend on a rate, since, except during the first fraction of a second during which the pressure is being applied, the rubber 'stays put'; nor in fact is the amount of deformation in the course of the squeezing the deciding factor. If the amount of deformation were the criterion, we should expect that a rubber would be equated in firmness to a bitumen if the elastic modulus of the rubber were numerically equal to the viscosity of the bitumen, in cases where the time allowed for squeezing was one second. This would follow from the fact that the elastic modulus is defined as the ratio of pressure to *amount* of deformation and the viscosity as its ratio to *rate* of deformation which, for a constant pressure, is given by the amount of flow in one second.

* Proper precautions are, of course, taken to allow for right and left-handedness.

In fact, it is found that only a third of a second's squeezing would be needed to give, on the average of many tests, an 'equal firmness' judgment between such samples.

It is concluded that the entity by which firmness is judged in such cases is neither a distance nor a rate but something in between. In comparing complex cheese-like materials with standard rubber cylinders the same thing happens, only here *time* is not as important as is consistency – for cheese itself it is about a fifth as important. This relative importance of time – one fifth in this case – has been called the 'Dissipation Coefficient'.

The dissipation coefficient of a cheese-like material can be calculated, then, from the massed results of a large number of squeezing tests in which the material is compared with standard rubbers or bitumens by enough people to eliminate the personal factor. But it can also be measured by compressing cylinders of the material under constant pressure on a machine. As the cylinder compresses, it increases in area and the force has to be correspondingly increased so that the pressure, which is the force on each square centimetre of surface, can remain constant.

The values of the dissipation coefficients agree excellently when measured by these two quite different methods, which means that out of all the complexities of 'firmness' we have evidently found something to satisfy the physicist which is independent not only of the observer but of the method of measurement.

What are these peculiar entities which lie, as it were, between distances and velocities, by which firmness is judged? Their mathematics had been worked out many years ago by Heaviside (now of radio fame), but their introduction into problems of measuring craftsmanship is entirely new.

It has been suggested that they are needed in this field for rather an interesting reason. For all practical and scientific purposes we tell the time by a clock. We say that two minutes are of equal length because the hand of the clock moves over equal distances on the dial in those times. But clocks

don't all tell exactly the same time. Even the rotations of the earth are very gradually slowing down. When we say 'slowing down', we must mean getting slower in relation to something else. The final criterion of equality of intervals of time is that light, out in open space, takes equal times to traverse equal distances, whose equality could be measured, in theory at least, by means of a foot rule. On this definition depends our concept of constant velocity and, in simple physical processes, the properties which are found to be constant, like the viscosity of our bitumen, are built up from velocities defined in this way.

But in more complex materials like cheese, clay or dough, the natural time scale is not dependent on rays of light, the rotations of the earth or the laboratory clock. Still less does the craftsman or anyone else handling the materials have a Newtonian clock (as it is called) in his brain. Quite other time scales are used and, if we insist on translating the results into terms of seconds and minutes (as we very rightly do), we must expect that our constant 'properties' of materials, or 'quasi-properties', as I prefer to call them, will be found to be built up of units which are not exactly distances, velocities or accelerations, but lie between these entities.

The relationships between these new ideas and some of the concepts of Relativity, which also modifies Newtonian physics, are interesting.

In conclusion, I would say that I believe this to be the sort of way in which Science can best fulfil its function. From the potter at his wheel to the philosopher at his desk stretches one single line of investigation. 'Pure Science' is a misnomer, since it implies that some science is impure. Science in the workshop without its counterpart in the study is equally meaningless. Measuring craftsmanship would seem quite effectively to illustrate the unity of scientific advance.

The Hearing of Insects

DR GABRIELE RABEL

PHYSIOLOGISTS who, guided by an understandable prejudice, searched for ears on the heads of insects, did not find any. But, unexpectedly, ear-like organs have been found in insects at odd places. How do these compare with our human ears?

Essential for our sense of hearing are two structures: (1) the drum (tympanum), a delicate, tightly-stretched membrane with a cavity behind it, (2) a long, spirally-coiled tube (the cochlea) which contains, attached to it along one edge, an extremely delicate ribbon, likewise spirally coiled, made up of about 24,000 elastic fibres which gradually decrease in length. These fibres are supposed to act like the strings of a piano, each responding to a certain tone, the longer fibres vibrating to the lower notes. This much quoted interpretation was propounded eighty years ago by Helmholtz, but, surprisingly, it has still the scientific status of a 'very plausible hypothesis'.

Now there are a few groups of insects which also have a tympanic membrane on either side of their body, with air-sacs behind. Grasshoppers, locusts, cicadas and certain moths carry them on their first abdominal segment, other moths on their thorax, while crickets, and according to some writers, termites, have their ears on the knees of their fore-legs. Roughly, one can say that those insects which make music (as distinct from mere noise) have also an organ to receive it.

But have they anything to fulfil the sound-analysing function of the cochlear ribbon? Scientists formerly believed they had. For one finds in all insects structures which consist of parallel elements – elongated spindle-shaped sensory

cells whose axes are prolonged into nerve fibres on the central side while on the other side they are in contact with the so-called 'scolopales' (pointed stakes). On the theory that the elongated parallel elements act as chords (strings) and have a 'tonus' or tension like strings, these structures have been given the name 'chordotonal organs', but they occur in all insects whether provided with a tympanum or not and they are no longer regarded as resonators. Yet some of them are associated with hearing and Eggers maintains that one can catch tympanal organs in the act of developing from chordotonal ones. Certain hairs and other body appendages are receptors for low frequencies transmitted through the substrate. Caterpillars and other larvæ have them too. And there is in a scientific paper a tale of larvæ who were directed in their motions by the chirps of their parents.

That some insects genuinely hear is no longer contested. Leydig observed drummers training on the Würzburg parade ground uproariously supported by a cicada chorus in the vineyards which stopped when the drummers stopped and started again when they did. The entomologist Collenette was present at a 'conversation' between a bird and a butterfly, their clicks being quite similar in quality and speed. 'The prompt response of the insect left no doubt that it was replying to the bird.' Musical conversations between two male insect songsters in which they go on for hours alternating rhythmically in their notes are often described, and a much admired feature in insects is their singing in concert. One of the singers may drop out for a while, but when he resumes the musical play, he is always in perfect synchronism with his fellows.

There have been endless controversies as to whether females are attracted to males by sound or rather by sight or smell or vibrations transmitted by the substrate, until by his most ingenious experiments with crickets, Johann Regen of Vienna disposed of all alternatives.

When he put a chirping but invisible male in competition

with a visible but silent one, the visible was unhesitatingly by-passed, even if the chirp came from a distant room over the phone. When he switched the current off, the female turned away. When he switched it on, she came, even if it meant fighting her way over a mountain of 150 cm. or through high grass.

Experiments with artificial imitation of insect song showed that male crickets and grasshoppers can be cheated only when they are new and quite inexperienced. When they grow older, they immediately stop their duets if a bogus male takes the place of a real one and tries to chime in in the same rhythm.

But how do insects discriminate between tone qualities if they have no sound analysing device such as mammals possess? Trying to answer this question, Dr Pumphrey, of Cambridge, broke new ground. His answer is: Amplitude Modulation.

Just as bats have applied the ultrasonic echo method since time immemorial, insects have operated with amplitude modulation long before engineers had any idea of its existence. Amplitude modulation comes about when an oscillation of constant frequency is interfered with by another, perhaps irregular oscillation so that owing to this interference the amplitude varies. In the wireless, a high constant frequency is produced by an electric oscillating circuit, a low one by music or speech. What can be the analogy in insects?

Grasshoppers or locusts produce their sounds by drawing a toothed ridge called a scraper across the sharp edge of a wing. Pumphrey thinks that the constant high frequency is given by the natural frequency of the wing, incited to its vibrations by the scraper, while the teeth of it provide the modulation. Not much work has yet been done to determine the frequency of each component. Pumphrey's evidence is indirect.

If a mammalian cochlea fitted with suitable electrodes is exposed to well-defined sound vibrations, it gives an elec-

trical response corresponding in frequency to the sound presented to it. But if an insect tympanum is thus examined, a pure tone, even in the range of its maximum sensitivity (5-20 kc. p.s.) produces a random electrical response which is the same for all frequencies presented and shows no time pattern (rhythm) at all.

When, however, a pure tone of 8,000 cycles p.s. was combined with a vibration of under 300 c.p.s., the nervous discharge consisted of bursts of activity which corresponded to the lower frequency. There is a striking contrast between the behaviour of a human and a locust ear in this case, though they are both equally sensitive to 8,000 cycles. If the pure high tone is combined with a low-pitched one, man hears a trill. But he notices little change if the lower frequency is widely varied, while he is sensitive to very slight variations in the high frequency. The contrary is true for the locust, according to the observed electrical responses. And this would imply that the insect can readily distinguish different modes of using the scraper while it is indifferent to the natural frequencies of wings.

It is a fact that sounds which seem identical to a human ear, can be easily distinguished by an insect and vice versa. In Regen's experiments, a virgin female cricket would approach a telephone even if the chirp appeared unrecognisably distorted to a human observer.

There is a theory that some classes of animals, including man, have auditory organs which respond to the pressure changes brought about by sound waves, but not to displacement changes, while for other classes, including insects, the contrary is true. In the case of those insects which have tympanic organs, the view that what they perceive is displacement not pressure is confirmed by the fact that these organs are capable of discerning the direction from which the sound comes. In the case of ants, which have no tympanic organs, Autrum confirmed this theory by a very original method. Sound was directed vertically downward upon a reflecting surface, thereby setting up standing waves. Ants

which walked on the reflecting surface were in a region of maximum pressure and minimum displacement, and such ants did not respond at all to sound. But at a quarter wave length from the wall is a region of maximum displacement and minimum pressure. When Autrum lifted his ant cylinder which had a wire net at its bottom, into one of the regions of maximum displacement, he noticed a strong reaction to the sound, a sudden anxiety, fearful running about, and continued restlessness.

Autrum also examined the sensitivity of longhorn grasshoppers to ultrasonics and found that their tympanal organ responded to frequencies up to 90 kc. p.s., even at very low intensity.

Approaching the Speed of Sound

PROFESSOR O. G. SUTTON

HITHERTO the behaviour of bodies moving at very high speeds through the air has been mainly the concern of the ballistician, but with the successful development of jet propulsion it is now possible to contemplate aircraft sufficiently powerful to be capable of reaching and even surpassing the speed of sound (about 760 miles per hour at normal temperatures). Speeds of this order are low for modern artillery whose projectiles travel steadily and attain high accuracy in their flight, and at first sight it is not obvious why it is difficult to reach the speed of sound in a piloted aircraft.

To understand completely what is involved in 'getting through the speed of sound' demands a knowledge of the complex and largely mathematical science of aerodynamics. It is possible, however, to describe in fairly general terms some of the difficulties involved, and the subject can be clarified by the use of a simple analogy which, is, in fact, more exact than might appear at first.

To begin with, the motion of an aircraft wing or other supporting surface creates a force due to the resistance of the air, and as long ago as 1809 Sir George Cayley, one of the pioneer English workers in this field, accurately described the problem of mechanical flight as that of 'making a surface support a weight by the application of power to the resistance of the air'. In aerodynamics it is customary to resolve the reaction of the air on a surface into two components, namely *lift*, which is that part of the force acting upwards at right angles to the surface, and is thus desirable, and *drag*, which is the component at right angles to the lift and which constitutes a loss since it resists the forward

motion of the surface through the air. An *aerofoil*, such as a wing or tail fin, is simply a surface of special shape which on being propelled through the air produces in certain conditions considerably more lift than drag. The problem of high speed flight is largely that of producing an assembly of such surfaces which can be relied upon to maintain a high lift/drag ratio and to remain stable in the exacting conditions met with as the speed approaches that of sound.

Drag

We commence by considering how drag, which represents energy wasted, changes with increasing speed. This is most simply done by comparison with the cooling of a hot body. Such a body loses heat (i.e. energy) in three ways – by conduction, convection and radiation. In the same way a body moving through air loses energy by *skin friction* (analogous to conduction), *eddy formation* (analogous to convection) and *wave formation* (analogous to radiation).

Skin Friction

Heat is conducted from a body by the molecules of air coming into contact with the hot surface and acquiring additional energy of vibration which is manifested as a rise of temperature in the layers of air near the surface. In the same way molecules of air adhere to the surface of a moving body and thus acquire from it energy of motion. This effect is called *viscosity* and acts in a very thin layer enveloping the body – the so-called *boundary-layer* of modern aerodynamics. This type of resistance occurs with all moving bodies and can only be reduced by making the exposed surface very smooth.

Eddy Formation

When a body with a sharply truncated tail (such as a shell) moves through the atmosphere at a moderate speed it is observed that the air flows smoothly around it until the tail is reached. At this point the stream is unable to make the

sharp turn required to get round the corner and the flow separates, forming a well-defined *wake*. In the wake masses of air coil themselves up into vortices or eddies, detach themselves from the body and drift away downstream. This is analogous to what happens with convection from a hot body when masses of warm air rise bodily from the surface and carry away heat to other regions. In the case of the moving body there are of course no corresponding differences in density, but the swirling eddies left behind in the wake have robbed the moving body of some of its energy to feed their own motion, and this is felt as an increased resistance, known as *form drag*.

If the tail is carefully tapered it is possible to prevent violent separation and so to avoid most of this loss, and bodies designed in this way are called *streamlined*. A streamlined body is, in fact, simply a body whose form drag is small compared with its skin friction – in other words, a body which leaves behind it only a small wake. At these speeds the importance to be attached to skin friction thus depends on the magnitude of the form drag; in a modern aircraft, for example, form drag is so small that it is worth while taking pains to get a smooth surface everywhere, but a high polish on the body of a car is a matter of pride to the owner and no more.

Wave Formation

The two types of resistance described above make up the entire drag* at speeds which are well below that of sound, and at these speeds the shape of the tail is more important than that of the head in designing a body of low resistance. As the speed of the body approaches that of sound, however, an entirely new phenomenon appears, which is akin to radiation in that it involves wave motion. Radiation from a hot body is usually unimportant at low temperatures, and similarly wave formation by a moving body does not really

* For an aerofoil it is necessary to introduce also the *induced drag*, i.e. the part of the total resistance which depends entirely on the lift.

begin to become important until the velocity is at least two-thirds that of sound (about 500 miles per hour at normal temperatures).

It is not at first obvious why the speed of sound should enter, but the reason becomes clearer when it is realised that at low speeds the air meeting the nose of the body is not appreciably compressed and made more dense but is deflected aside, something like a good-natured crowd giving way to a slowly moving car. At higher speeds the air near the body has, crudely speaking, no chance to get out of the way and is compressed. When such sudden compression takes place the air near the body responds by passing on the blow and the disturbance is propagated throughout the fluid as a *wave*, consisting of a succession of condensations and rarefactions. If the disturbance is small the result is an ordinary sound wave, but if the blow is severe, such as occurs with a massive body rushing rapidly through the air or with an explosion, the result is a definite atmospheric discontinuity called a *shock wave* which travels initially with a speed somewhat greater than that of sound. As it moves, the shock wave continuously loses energy and slows down, ultimately degenerating into an ordinary sound wave.

Thus in the case of an aircraft or a projectile moving at a speed just below that of sound the air at the nose is compressed and a spherical wave front rushes ahead, the whole disturbance growing like a soap bubble. With increasing speed the body approaches nearer and nearer to the wave front until ultimately it catches it up and thereafter the wave remains attached to the nose and is carried along with it, forming a well-defined cone with its apex at the nose. These wave fronts are extremely sharp – it can be shown mathematically that the region of highly-compressed air is usually not more than a small fraction of an inch in thickness – and they therefore photograph well (see plate 45) and even (as happened during the bombardment of London by V-weapons) have been seen, by favourably-placed observers, as a thin curved line rising from the scene of a distant explosion.

Compressibility

Phenomena of this sort are said to be due to *compressibility* and give rise to what is known in ballistics as 'head resistance' and in aerodynamics as *wave drag*. Because of their importance in gunnery the effects of such wave formation on resistance are now well established. In the narrow zone of speed known as the *transonic region* (between about 600 and 800 miles per hour at normal temperatures) the resistance changes extremely rapidly with velocity, suddenly shooting up to a high value and then, rather more slowly, steadying down to a more gradual rate of increase as the speed becomes highly supersonic. This sudden jump in resistance indicates the extra energy used in compressing and setting in motion the air to form the system of shock waves at the nose and other parts of the body. At these high speeds the shape of the head becomes of considerable importance and with a high velocity shell most of the energy lost in overcoming air resistance is 'radiated' away in shock waves. This is in sharp contrast to what happens at lower speeds when the main loss of energy is associated with the formation of eddies in the wake. Figure 1 shows diagrammatically these various sources of loss.

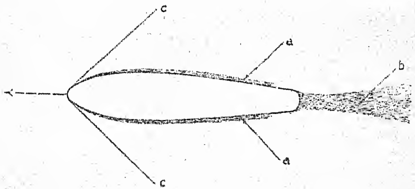


Figure 1—Sources of resistance on a moving body:
(a) boundary layer (skin friction);
(b) wake (eddy formation);
(c) shock waves (wave resistance).
Shock waves may also form at other points on the body.

The Mechanism of Lift

We now consider the other – and useful – part of the reaction of the air, namely the lift force which actually causes an aircraft to fly. At subsonic speeds lift can now be said to be well understood, thanks chiefly to the pioneer work of F. W. Lanchester in the early years of this century. Like form drag it is connected with rotary motion or circulation in the air, but now in a well ordered form.

When an aircraft takes off, its aerofoil supporting surfaces start moving through the air at a small angle to the horizontal, and almost the first thing that happens is that each wing sheds an eddy (called the 'starting vortex') at the rear edge. The reaction to this vortex causes circulation around the aerofoil with the result that the air moves more rapidly over the upper cambered side than over the lower flat side. By Bernoulli's theorem this causes decreased pressure on the upper surface and increased pressure on the lower surface, so that the wings are both 'sucked' and 'pushed' upwards, thus giving the necessary force to make the heavy machine rise. As the angle of incidence increases, the lift also increases and the aircraft is able to climb, but if the tilt is made too large the flow on the upper surface separates and eddies are formed, resulting in a sharp drop in lifting power. When this happens the aircraft is said to *stall*.

So far we have only considered speeds at which the effects of compressibility are too small to be of importance, but as the speed of the air-flow over the wing approaches that of sound a new phenomenon appears. The pilot is able to increase or decrease the lift by altering the angle of incidence and at the lower speeds the rate of change of lift with incidence is usually fairly constant, but near the speed of sound this rate of change suddenly drops to a very low value together with a large decrease in lift itself. In this critical region of speed the pilot is thus faced not only with a rapid rise in resistance but also with a sudden loss of lift and control, a phenomenon known as *shock stall*. There are also other disturbing effects, making it difficult for the aircraft

to remain on an even keel (chiefly due to the fact that flow conditions are not exactly the same over the wings and tail planes) so that, taken altogether, the dangers of high speed flight are not difficult to imagine.

The Mach Number

At this point it becomes necessary to introduce a concept of major importance in the dynamics of high-speed flow. It can be shown by fairly simple considerations that all phenomena at high speeds depend not on the absolute velocity of the body but on the so-called *Mach number* which is the ratio of the air speed to the velocity of sound. (That is, a Mach number less than unity indicates a subsonic speed and one greater than unity, supersonic speed. The transonic region covers, very roughly, the range of Mach numbers between about 0.75 and 1.1). Since the velocity of sound changes quite considerably with air temperature, the Mach number depends not only on the aircraft speed but also on the height, the season and the locality of the flight.

The phenomenon which we have been discussing first appears at a certain Mach number known as the *critical Mach number* whose exact value depends upon a number of factors. There is also some evidence that if the speed is high enough matters become easier again, so that there may be an upper as well as a lower critical Mach number, or in other words, safety lies in keeping well away from the transonic region of speed.

The Design of High-Speed Aircraft

It is an unfortunate fact for the understanding of high speed flight that not only is the mathematical theory of fluid motion at these velocities extremely difficult and only partially developed, but also that phenomena at high velocities are often quite contrary to what experience at every-day speeds would lead one to expect. (One of the most striking examples of this is that whereas at low speeds, as we have seen, a fluid cannot easily turn a sharp corner

without the flow separating and forming eddies, at supersonic speeds there are apparently no such difficulties and the fluid is able to get around quite smoothly). If however, certain facts of compressible flow theory are accepted it is possible to explain in a short space some, at least, of the factors which influence the design of high-speed aircraft.

To attain very high velocities in a practicable aircraft it is obvious that wave drag must be reduced to a minimum. At low speeds the drag of a wing is not greatly affected by its thickness (up to a limit) but the wave drag of a wing moving at high speeds is proportional to the square of the thickness plus a term proportional to the square of the lift. This means that supersonic aircraft should have thin low lift wings, requirements that conflict with other demands for great structural strength and considerable weight-carrying power.

The necessity of keeping the flow over the wings below the critical Mach number has meant a considerable change in the shape of aircraft. As we have seen, the lift/drag ratio collapses very rapidly once the Mach number M reaches the critical value (say $M=0.75$). In its simplest form the mathematical theory indicates that the velocity which matters in calculating the effective Mach number for the wing is the component of the speed perpendicular to the leading edge. With straight wings, this velocity is obviously the same as the forward speed of the aircraft, but if the wings are given a certain amount of *sweepback* (Fig. 2), the velocity perpendicular to the leading edge will be only a fraction of the forward velocity. On this simple theory, as indicated by Busemann in 1935, if M_0 is the Mach number for the aircraft as a whole, the effective Mach number for the wing will be $M_0 cos\theta$, where θ is the angle of sweepback. This means that M_0 itself may be above the critical value with the effective Mach number for the wing still safely below the critical, or in other words, the use of swept-back wings raises the critical Mach number for the aircraft and allows the higher speeds to be reached without the danger of shock stall.

The more exact theory shows that the advantage is not

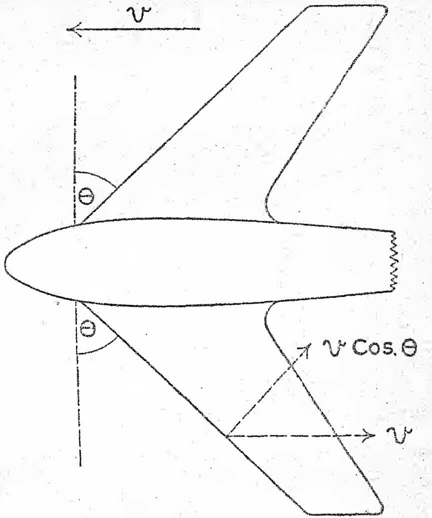


Figure 2—Aircraft with sweptback wings.
v = velocity of the aircraft forwards, or of the air flow over it in the opposite direction.
$v \cos \theta$ = velocity of air flow perpendicular to the leading edge of the wings.

quite as great as indicated by the simple cosine law given above, and there are also certain compensating disadvantages introduced by sweepback, but the net effect is undoubtedly beneficial. There are also other variants of the idea, notably the 'delta' or triangular wing, but the discussion of these is beyond the scope of the present article.

Conclusions

Prophecy in scientific matters is perhaps only slightly less hazardous than in other fields of human activity, but it seems highly probable that safe supersonic flight will be attained and may even become commonplace in the next decade or two. Simultaneously, it is likely that designers will turn their attention more and more to the 'flying wing' type of aircraft (see plates 44 and 46) and a relatively few years may see the disappearance of the conventional fuselage and tail. On the purely theoretical side progress is more difficult to foreshadow, but the considerable advances made in recent years by Taylor and Maccoll in this country and by Kármán and Moore in America on the wave resistance of projectiles are encouraging signs.

Postscript

The non-specialist reader who wishes to know more of these matters may find this difficult; the writer does not know of any simple and non-technical but accurate account of high-speed flow which includes the latest advances. For the reader with a knowledge of mathematics the best general statement of the present position is undoubtedly that given by Kármán in the 10th Wright Brothers Lecture to the Institute of Aeronautical Sciences and printed in the *Journal of Aeronautical Sciences* Vol. 14, No. 7 (July 1947), but to follow this account demands a considerable knowledge of aerodynamics.

Research Report

A. W. HASLETT

Southern Stars

THE whole of stellar astronomy is based on a very limited number of possible kinds of measurement. The most obvious is measurement of position. This is the foundation of navigational astronomy, and was implicit in the invention of the calendar. The next oldest is measurement of apparent brightness. This is due to Hipparchus of Nicaea who, about 130 B.C., built an observatory at Rhodes, and made observations on about 1,000 bright stars which could be seen with the naked eye from the latitude of the Mediterranean. It is a type of knowledge which is normally taken for granted, but which enters directly into many of the more abstruse deductions which can now be made about the physical state of stars. Together with measurements or estimates of distance, it enables the absolute or true brightness of stars to be calculated, and this in turn ties in with the detailed analysis of the radiation emitted by stars, which the spectrograph makes possible. For example, the accepted classification of stars is based on a comparison of absolute brightness and spectral type. There is also a 'law', due to Sir Arthur Eddington, which enables the mass of a star to be deduced from its brightness. It follows that measurements of apparent brightness, which astronomers as well as laymen are apt to take for granted, occupy a key position in the whole structure.

Such is the background to a major and long-term undertaking on which Dr R. H. Stoy, Chief Assistant at the Royal Observatory, Cape of Good Hope, has lately reported to the Royal Astronomical Society. What is being done is nothing less than to determine the apparent magnitude or bright-

ness of 75,000 southern hemisphere stars, and to link these through further observations at Cambridge with the standard series of stars in the neighbourhood of the North Pole to which all measurements of stellar brightness are referred. Also, because of this new and more accurate joining-up between northern and southern stars, the way will be paved for the extension of the work by other southern observatories – besides, possibly, leading to some apparently very necessary re-examination of existing northern hemisphere observations. It is quoted here as an example of a humdrum but essential type of astronomy of which little is normally heard.

The method of classification traces directly from that first introduced by Hipparchus. He began by describing the brightest stars which he knew as being of 'the first magnitude'. Stars of the next step down in brightness which he could recognise he called 'second magnitude', and so on down to the faintest which he described as 'sixth magnitude'. Rough and ready though it was, the system which he introduced has survived, with necessary modification, owing to the chance circumstance that the eye responds equally to equal proportionate increases in brightness over quite a wide range of light intensity. It was found later that his scale of magnitudes corresponded roughly to increases of 2.5 times in apparent brightness, and the modern scale is still very close to this figure. It has been so chosen that a hundredfold increase in brightness corresponds with five steps in magnitude – which gives a brightness increase for one magnitude of 2.512. But, as already indicated, the final reference is to a sequence of standard stars, near the north pole, which are internationally recognised for the purpose.

The present programme at the Cape was due in the first instance to Sir Harold Spencer Jones, now Astronomer Royal at Greenwich, but formerly H.M. Astronomer at the Cape of Good Hope. A serious start was made in 1938, and on the main work of inter-comparison 25,000 out of the original 75,000 stars have now been covered. On the other

hand, various special additions to the original programme have added about another 45,000 to those on which measurements are to be made. For 'joining up', the original intention was to make use of previous brightness determinations on equatorial stars, which can be observed from both hemispheres. In practice, it has been found that no sequence of intermediate stars is available, of which the brightness is known with great enough accuracy to serve as the necessary link. The task of linking up is therefore being undertaken by Prof. R. O. Redman who, while at the Radcliffe Observatory, Pretoria, had already co-operated with the Cape Observatory in working out a series of southern standard stars which provide the immediate reference for the whole Cape observations. He has lately taken over the direction of both the university observatory and the solar physics observatory at Cambridge; and he has agreed to complete, at Cambridge, the necessary linking up with the north polar sequence of international standard stars. This will probably take about two years; but, when completed will be applicable via the Cape to all stars visible in the southern hemisphere.

(Stoy. *Monthly Notices Royal Astronomical Society*, in the press.)

X-ray Progress

Procedure for the generation of X-rays of any specified energy is to accelerate a beam of electrons to the required energy, and then stop it by allowing the electrons to hit a metal target. In *Science News V*, it was stated that the Telecommunications Research Establishment at Malvern had attained the distinction of being the first laboratory in the world to make a 'synchrotron' work – a 'synchrotron' being one possible engineering device for the acceleration of electrons – and that a larger piece of equipment capable of producing 30 million volt X-rays had been designed. Several new pieces of information can now be added. One is that two production equipments to this design are being built for the Medical Research Council. They are to be

installed in Cambridge and at the Cancer Hospital, London, respectively – a disposition which will ensure that both the biological and the medical effects are adequately examined. The second is that a 'synchrotron' capable of accelerating electrons, not to 30 million volts, but to 140 million volts, is being built by the same firm for the Clarendon Laboratory, Oxford. Finally, the Telecommunications Research Establishment, which first made the 'synchrotron' work, has again demonstrated its technical competence by a similar success with a quite different type of equipment. In this, known as the linear accelerator, the electrons are accelerated by the very simple method of allowing them to travel down a metal tube in the company of centimetre radio-waves. The idea, certainly, has been common talk amongst physicists ever since the wartime development of practical and compact radio transmitters working on these very high frequencies. But, again, it is to the credit of the Malvern establishment that they should have made the idea work. It is not just a case of 'injecting' a beam of electrons into any metal tube down which radio waves happen to be travelling; but of providing precisely calculated conditions such that electrons and radio waves will travel together and in step. In the first section of the Malvern equipment to be completed, electrons have been 'injected' into such a tube at the comparatively modest energy of 45,000 volts, and have been accelerated to the equivalent of 538,000 volts. This compares with a design figure of 540,000 volts. The significance of this close agreement is that the 40-centimetres length of tube, or wave-guide, which has so far been used, is only the first section of a very much longer accelerator. When complete this will be some 20 metres in length; and, with the same radio output, the electrons should be accelerated roughly in proportion. With the single section, so far tested, less than 2% of the energy of the radio transmitter was transferred to the electron beam, the remainder being wasted. With the full projected length, it is calculated that an efficiency of 80% could be secured. It is felt by physicists that some such approach

offers the most economical method of attaining the highest energies, and this may also be true at the level of 30-50 million volts in which doctors are chiefly interested. But, whichever the final method, the Medical Research Council's two 'synchrotrons' will not have been wasted, since the immediate need is for experience at these greatly increased energies. For this purpose the method of production of the X-rays is immaterial, while the 'synchrotron' has the practical advantage of being relatively compact.

(Fry, R. S. Harvie, Mullet and Walkinshaw, *Nature*, 1947, 160, 351.)

History of the Earth

One more has been added to the series of shocks which physics from time to time administers to physical geology. The first was Lord Kelvin's famous calculation, based on the known facts of heat conduction and cooling by radiation, that the earth's crust would have been too hot to permit the formation of oceans at any period before about 40 million years ago. This was on the supposition – later proved false by the discovery of radio-activity – that the earth contained no source of heat within itself which could make good in part the inevitable loss of heat by radiation from the surface. The latest such shock is due to the realisation that radioactive potassium must, in the past, have made a very much bigger contribution to the earth's heat output than either uranium or thorium. It has been administered by E. Gladitsch and T. Gráf of the University of Oslo, and it affords quite a salutary demonstration of the difficulties attached to any calculation which seeks to determine conditions in the remote past from those prevailing at the present time. The change, compared with previous calculations, is due to the fact that whereas both uranium and thorium break down at a relatively slow rate, even compared with the 3,000 million years' estimated lifetime of the earth, radio-potassium breaks down considerably more quickly. The effect, working backwards in time, is naturally cumulative. If uranium and thorium had been the only significant sources of heat within

the earth, the rate of release would at no time have been more than about half as great as it now is. But to account for the present surviving proportion of radio-potassium (in round figures one in every 10,000 potassium atoms) it is necessary to suppose that the initial supply must have been 1,000 times as great. This in turn leads to the conclusion that the release of heat from radio-potassium must have been 200 times greater than from uranium and thorium combined. The full implications to geology of these rather startling readjustments must take time to assess. What is more worth while to point out is that this very big increase in the estimated contribution of radio-potassium has been brought about by two comparatively small, if overdue, revisions in the numerical values obtained in some laboratory experiments in 1934. One is that the energy released in the breakdown of a single atom of radio-potassium has been increased by a factor of seven or eight. The second, and more important, is that the rate of breakdown of radio-potassium atoms has been increased by a factor of about three. Yet if these considerable, but hardly spectacular, alterations are applied cumulatively over a period of 2,400 million years – the length of time to which the calculations refer – they lead to figures of a quite different order from those previously quoted. It should perhaps be added that the various methods by which the age of the earth has been estimated are not affected by these considerations; and that, in view of their importance to geo-physics, an independent check of the present revised figures for radio-potassium is clearly desirable.

(Gladitsch and Gráf, *Physical Review*, 1947, 72, 640.)

Submarine Gravity

The use of submarines for the making of gravity surveys beneath the sea is due to Prof. Vening Meinesz of Holland, who also designed the first gravity meter sufficiently sensitive and stable to be usefully employed under such conditions. He applied the method, during a series of prolonged trips

in a Dutch submarine, to measure gravity anomalies in the areas both of the East and the West Indies, and drew some conclusions about the probable growth of new mountain chains beneath the sea. Shortly before the time of Munich, the Department of Geodesy and Geophysics at Cambridge University drew up plans for a more limited investigation of conditions round the edge of the 'continental shelf' which separates Europe proper from the Atlantic. The Admiralty agreed to provide a submarine, and the expedition was planned, and even begun, in 1938. But within 36 hours of leaving port, the Munich crisis developed, and the submarine was recalled. Further plans were held up until August, 1946, when the submarine *H.M.S. Tudor* was made available for the resumed expedition, and still more lately a preliminary report has been issued.

Previous information was that, whereas sediments carried out to sea by rain and rivers had resulted in a relatively level surface to the sea bed immediately round Europe, drooping only slowly towards the edge of the 'shelf', the underlying basement rocks fell away more rapidly, so that near the edge of the 'shelf' the thickness of sediments might reach many thousands of feet. This was established by Prof. M. Ewing for the eastern seaboard of the United States, and by Dr E. C. Bullard of Cambridge for the mouth of the English Channel. The supposition, which remained unproved, was that the growing weight of sediment, driven outwards from the land by the action of the tides, had caused the basement rocks to sink more deeply into the semi-molten layer beneath, further sediment being again deposited at the lower level. The theory, in short, was that the level of the basement rocks was determined by gravitational equilibrium. The object of the *H.M.S. Tudor* expedition was to test this theory by measurements of the intensity of gravity towards the edge of the 'shelf'. Four different areas were examined, and in three of them measurements and theory were in almost perfect agreement. These were off the mouth

of the English Channel, and to the west of Ireland and Scotland respectively. In each case equilibrium had been maintained; and it appeared that, without sediment, the original depth of the basement rock would have been about half as great as it now is. That, therefore, was the extent of sinking. Only the fourth area, the Bay of Biscay, was not in equilibrium. Anomalies here were attributed to horizontal pressure connected with the coastal ranges.

(Browne, *Observatory*, 1947, 67, 173.)

The Heart in Starvation

It is no secret that the experience of doctors and research teams, both in occupied Europe and in the rehabilitation of those who had been in Japanese prisoner-of-war camps, resulted in a good deal of new information about the behaviour of the body under near-starvation conditions, and also during rehabilitation. In addition, many of the results are now available of an experiment which was carried out in the Laboratory of Physiological Hygiene of the University of Minnesota, with fit young Americans as volunteer subjects.

The most general point which has emerged is that the body can balance food intake and energy consumption at a considerably lower level than had before been realised, and when this position has been reached no further loss of weight takes place. Loss of weight in itself reduces the amount of fuel – from food or fat reserves – which must be 'burnt' to maintain normal bodily processes. In addition, the individual learns to keep his avoidable output of muscular energy to the lowest level possible. Both factors help towards the attainment of a new balance, and both in the Minnesota experiment and in the Hong Kong civilian internment camp this was reached when weight had fallen by one quarter from its original level. Equally, it was found during rehabilitation that time was needed for a normal balance of chemical activity to be re-established. Professor Beattie, for example, of the Royal College of Surgeons, has pointed out

that during the first stages of rehabilitation, practically the whole of the protein eaten as food, which one would normally expect to be largely utilised in tissue replacement and 'building up', was in fact burnt as 'fuel' – even although enough Calories to meet energy requirements were being otherwise supplied.

The most detailed and interesting findings are, however, those at Minnesota on the response of the heart. The traditional assumption in the past has been that, during starvation or near-starvation, the heart and other vital organs were 'protected' from damage for as long as a necessary minimum of nourishment was available. The experience of the 32 fit young men who went through the Minnesota experiment shows clearly that this is not the case. The outline of the test was that they were observed first through three months of normal diet, during which period they required on the average 3,200 Calories for energy balance; then for six months with a food intake of 1,700 Calories, by which time they had lost 24% of their original weight; and finally, during rehabilitation, for three months of controlled diet, and a further five during which they could eat what they liked. X-ray photographs, taken from different angles, were used to record the physical volume of the heart at all stages, and other measurements enabled the output of work by the heart to be calculated. It was found that, when adjustment to semi-starvation had been completed, the volume of the heart had been reduced by 16%, the number of strokes per minute by 32%, and the heart's output of physical work by as much as 49%. Also, the margin of safety represented by unused oxygen, still left in the blood after circulation, had been brought down by one half. With such drastic changes, a quick return to normal would scarcely be expected. In practice, three months of controlled feeding sufficed only to get the heart nearly, but not quite back to normal in size, with practically no improvement in its capacity for work. Nor did the inclusion of extra vitamins and protein in the diet make any noticeable difference. By

the end of five months, of which the last two had been on unlimited diet, the heart size was slightly greater than it had been originally, but capacity for work was still 10% below normal and only half of the lost margin of oxygen safety had been made good. Finally, at the end of 32 weeks, only very slight signs of abnormality could be detected.

Climate and Food

Evidence suggesting that dietary preferences are automatically adjusted to suit climatic conditions has been obtained at the Medical Clinic of the University of Pecs, Hungary. The basis of the experiment was to offer different groups of mice the choice of three different food mixtures at three different temperatures. Each food mixture was composed as to one-third of a standard mixture, which provided in itself the whole of the accessory factors needed for health, while the remaining two-thirds was either starch, milk protein (casein) or fat. The mice were free to eat as they chose, and at normal room temperature took roughly two-thirds of their total calories from the fatty food mixture. The main comparison was, however, between their feeding habits at moderately low temperatures (50-52 degrees F.) and approximately tropical conditions (84-91 degrees F.). The interest of the experiment was that, although differences in total consumption ranged from about 20 to about 40%, in all cases practically the whole difference was due to an increase or decrease in consumption of starch, the amount of protein and fat eaten remaining approximately constant under all conditions. The mice, in other words, did precisely as any dietetic expert would have advised – taking as much protein and fat as they needed, and then using starch as a 'buffer' to make up the balance of their calorie requirements. A generation ago, 'instinct' would no doubt have been put forward as the explanation. Today, some form of chemical control appears more plausible. And since the activity of the thyroid gland may increase as much as three-fold at low temperatures, it is suggested that it is through the

thyroid gland that food tastes are thus regulated. But, although the experimental facts appear clear enough, it should be pointed out that the suggested explanation is no more than a speculation.

(Donhoffer and Vonotzky, *American Journal of Physiology*, 1947, 150, 329.)

Control of the Tsetse Fly

Control of the mosquito and the locust having been proved practicable, hopes have naturally been aroused that the even more difficult and equally important problem of the tsetse fly would also be solved. As the carrier of nagana disease of cattle, this is generally regarded as the most serious remaining brake on the future progress and development of tropical Africa. Exceptional interest was therefore taken in a recent film demonstration by Dr P. J. du Toit, Director of the Union of South Africa Veterinary Service, of the use of D.D.T. from the air against the tsetse fly.

D.D.T. was first tried in the form of a liquid emulsion, sprayed from the air. Thus used, it was shown by fly-trap counts to reduce the tsetse fly population in the proportion of 9,000 to 600 three months after treatment. This was a big improvement, but not enough to achieve the intended purpose of local eradication. To get better results, it was realised, it would be necessary to get the D.D.T. to the underside of the foliage, where the fly chiefly sheltered. Further experiments were therefore carried out in which the heat of the engine was used to vaporise the D.D.T., and the insecticide ejected from the aircraft as a fine smoke. With this treatment the fly population in the same area was further reduced in the proportion of 600 to 3 – so that the overall reduction was now about 3,000 to one.

Procedure is for aircraft to fly at a height of between 50 and 75 feet – little more than tree-top height – and in arrowhead formation. Each aircraft can cover a strip of 70 yards in width, and a flight of six aircraft has been used. It has been found that the slight breeze of early morning helps to

carry the resulting smoke blanket in under the trees. But by ordinary standards conditions must be calm. Practice so far has been to make six successive flights at fortnightly intervals, and to treat residual fly patches with smoke generators carried by hand through the bush and operated from the ground. Cost is estimated at 18s. per acre – small enough, certainly, in relation to farming output, but large when multiplied by the total acreage of tropical Africa.

Fortunately for Dr du Toit, the Union problem with which he is immediately concerned can be treated in isolation from the wider one of tropical Africa. In place of almost unlimited areas, he has to deal with about 1,000 square miles of active infestation, split up into some three different areas, all in Zululand, and a further perhaps 4,000 square miles of potential infestation. Also, between the most northerly of these Zululand areas and the main belt stretching from east to west across the whole breadth of Africa, there is a gap of about 200 miles in which no tsetse have been found in recent years. The aim, therefore, is complete eradication within these comparatively limited areas, and for this purpose the cost of the air treatment which has been tried would not be unreasonable. For the moment, treated areas are being 'sealed' by the total removal of all bush within a two-miles belt, and a watch is being kept to see what happens to the small remaining fly population. It was possible, Dr du Toit thought, that natural enemies would do the rest – but not all his audience felt the same optimism.

Of the other possible methods of control which have been attempted, game extermination has aroused the greatest controversy. The basis for it is the supposition that tsetse fly (of which, incidentally, there are twenty different species) can obtain nourishment from wild game as well as from cattle. It is commonly believed, therefore – and with some reason – that wild game act as a reservoir both of the fly and of the nagana disease which the fly carries. It has been pointed out, however, that further research is needed to establish the contribution made by different game species,

and that there is no case on scientific grounds for the indiscriminate slaughter of all alike.

Prof. P. A. Buxton of the London School of Hygiene and Tropical Medicine, who presided at Dr du Toit's film demonstration, drew attention also to the fact that in East Africa selective clearing of as little as five per cent of the bush had been enough to bring about complete local elimination of the fly. The difficulty is that since local conditions naturally vary, and that over quite small areas, a series of detailed studies by 'fly-minded' investigators would be necessary. Similarly, under the savannah conditions of Northern Nigeria, where during the hot season the tsetse fly barely survives, a relatively small amount of clearance can produce big results. The feeling of the meeting was that, although no single method is likely to solve the whole problem, Dr du Toit's smoke-spray attack is 'well worth trying under as many conditions as possible'.

Midge Investigation

Nearer home, the Universities of Glasgow and St Andrews have lately combined to begin a seven-years' investigation of the midge, the activities of which have been more taken for granted than studied. The fact, however, is that midge infestation could be a serious handicap to the development of much of the western Highlands, and that comparatively little is known about its biology. This applies both to the distribution of species, of which some thirty are recognised, although most of the human biting is attributed to one, and to the life-cycle and habits of the insects. For example, although the adult insect can be kept alive for up to two months in the laboratory with access to carbohydrate food, it is not known whether under natural conditions the developed insect takes any further food than the blood meal needed by the female for the development of her eggs. Little is known either about the conditions under which eggs are laid, although damp soil is thought to be 'probable'. A hutted laboratory has been established, as a centre for

field studies, at Rossdhu, Loch Lomond, and various laboratory investigations are being carried out in the University of St Andrews.

Embryo Nutrition

Increased use is being made of the radio-active tracer method of studying the developing embryo. It is particularly well suited to this purpose since the capacity to 'label' atoms of particular chemical elements in the mother is precisely what is needed for the investigation of the transfer of those same elements to the embryo. Earlier work in the United States, mainly between 1941 and 1942, did little more than illustrate the scope of the method and was interrupted by Pearl Harbour when the most interesting stage appeared likely to be reached. One such test, with radio-calcium in mice, confirmed that there was a transfer to the foetus of calcium which had previously been 'fixed' in the bones of the mother, and showed that the last calcium to be absorbed was also the first to be released for transfer. This was in the Crocker Radiation Laboratory at Berkeley, California, which later took a leading part in investigating the absorption of plutonium and fission products formed in the uranium pile in relation to safety precautions for atomic energy workers. Another such experiment, carried out at Rochester University, showed that the time interval between the feeding of iron to the mother and the appearance of radio-activity in the blood of the embryo was only forty minutes. The text-book description of the formation of blood cells in the embryo was that the red cells of the mother travelled as such through the umbilical cord to the embryo, and were there broken down, and the iron which they contained re-used in the formation of the embryo's own red cells. But the shortness of the observed interval made it unlikely to the point of impossibility that this explanation could be correct. Finally, Dr P. E. Nielson of the University of Wisconsin carried out a similar and preliminary study of the transfer of phosphorus.

Greater availability of radio-active supplies is now leading to an increased interest in the method, for this as for other research purposes, and at a recent meeting of the Biochemical Society, Dr G. Popják of the National Institute for Medical Research described the results of a more detailed investigation in the case of phosphorus. The problem is similar to that raised, and already partly answered, in the case of iron. Can the embryo make use of simple inorganic materials, and if so how are they converted into organic form? In particular, what is the origin of the complex phospholipids – fat-like substances – needed by every cell? Dr Nielson's work had already suggested that inorganic phosphorus could be used. Dr Popják has now shown further that both from the liver and the placenta of the embryo it is possible to extract phospholipids which, weight for weight, are more highly radio-active than the blood plasma of the mother, into which the test injection had been made. This could scarcely happen unless in these organs, at least, the embryo was doing its own building up. Similar experiments have been carried out on rats, guinea pigs, and rabbits, and they all support the same conclusion. There is also more limited evidence suggesting that all the organs of the embryo, and not only the liver and placenta, are capable of the same building up process. This was obtained by direct injection of the embryo with radio-active phosphate.

(Popják, *Biochemical Journal*, in the press.)

Ultrasonics

DR. GABRIELE RABEL

THE terms 'Ultrasonics' and 'Supersonics' have been buzzing about recently in the news, and especially the 'Bat Case' has aroused considerable interest. The subject of this article is to give a brief account of what ultrasonic waves (USW) can do, but as I have noticed here and there some confusion attached to the terms ultra- and supersonic, it seems desirable to begin by clearing the terminological ground.

Ultrasonic vibrations are of the same type as sound vibrations, but have a frequency too high to be sensed as sound by the human ear.

The threshold of audible sound is 30 vibrations per second. Its upper limit is said to be 20,000, but for old people it is considerably lower. What is above 20,000 is not audible to the human ear, but is ultrasonic.

In papers written in English these high frequencies are often described as 'supersonic', but 'ultrasonic' is preferable for three reasons: this word has chronological priority, it matches the German 'Ultraschall' and the French 'ondes ultra-sonores' and airminded people use the term 'supersonic' for a velocity not for a frequency. What do they mean by a 'supersonic velocity'? They tell us, it makes a difference whether a jet of gas or a bullet or aircraft moves through air 'faster than sound' or slower. They do not mean that it may be important to hear an aircraft before it arrives, but that the aircraft (or air-jet) itself is decisively influenced by its own 'supersonic' velocity. How on earth does sound come into the problem? The answer is: not at all.

Every pressure change, every disturbance, periodic or non-periodic, spreads in air with the same velocity. Sound is a pressure change. Therefore sound, too, spreads with the

same velocity. But as this latter fact is irrelevant, the term 'supersonic velocity' is misleading, and I propose to use the non-committal terms 'Supervelocity' and 'Subvelocity' for speeds above and below the general 'Disturbance Velocity'.

If an aircraft moves with subvelocity through air, the disturbance created by it runs ahead and prepares the way for the coming traveller. If, however, the aircraft travel faster than the disturbance it has created, the result is that a cone of highly-compressed air (called a shockwave though it is not really a wave) envelops the bow of the craft and acts as a resistance.

Similarly if an air-jet moves with supervelocity, entirely novel conditions arise. The jet breaks into segments, and if a tiny cavity, say a tube of 1 mm. diameter and the same length, closed on one end, is introduced into certain parts of these segments, the cavity hurls the air back periodically and the periods are of ultrasonic frequency.

This is one way of producing USW. One further gets them from a Galton whistle, or jingling keys, or from Magnetostrictive or Piezoelectric Oscillators.

Magnetostriction is the periodic contraction of a nickel rod in an alternating magnetic field. The end of the rod emits high frequency waves.

Piezoelectricity is an electric charge developed on the surface of certain crystals, including quartz, under pressure. If, conversely, an alternating voltage is applied to a plate cut out of such a crystal, the plate contracts and expands periodically, causing compressions and rarefactions in the surrounding medium.

Every body has a 'natural frequency' (*Eigenschwingung*). If the rhythm of the externally imposed alternating voltage coincides with the very high natural frequency of the quartz plate, the maximum effect, Resonance, is obtained, and the vibrations thus produced have enormous and astounding effects.

The energy of sound waves is proportional to the square of the frequency; that is why vibrations up to a million cycles

per second or more are so powerful. E. Meyer has computed that if an orator talked without interruption for 150 years, the sound energy expended would be just enough to boil water for a cup of tea. But water traversed by USW boils an egg in a jiffy. R. Wood tells us that the acceleration at the surface of a vibrating crystal, though the amplitude be only 0.008 mm., can amount to 40,000 kilometres per second per second.*

Wood and Loomis reported, among other spectacular results, that in a dish of oil with a piezoquartz at the bottom, the oil drops surged up to 40 cm. height as from a miniature volcano. They worked with 2 kilowatt power at 50,000 volts. Later Grützmacher constructed piezocrystals in the form of spherical mirrors and at the focus of such a quartz mirror a power of only ½-kilowatt at 2,400 volts makes the oil jump even higher.

A recent development is the construction of ultrasonic lenses.

Up to World War I, piezoelectricity was a laboratory curiosity. In 1917, Langevin constructed a device which made it possible to send out a narrow beam of USW under water for signalling and for determining the position of submarines by the echo method. USW are well suited for the purpose because they are very little absorbed in water – much less than in air.

The echo principle is also used for measuring the depth of the sea. Utilising multiple echoes it is possible, not only to get a profile of the sea bottom, but even to decide whether it consists of sand, mud or clay.

George Godwin in his book *Marconi* describes an interesting Admiralty order received in 1942 for a Submarine Buoy radiating ultrasonic signals with changing pulse rates to prevent identification, sufficient for bearings to be taken

* If a body moved out into space with such an acceleration, it would acquire a velocity of 40,000 km. p.s. in 10 seconds and would by this time be 2 million km. away.

on, but not to be picked up by the enemy, blowing itself up if fished up, transmitting every one or two hours day and night but only for 14 days in the 28, with the task of acting as Radio Underwater Lighthouses. In Sicily and at Anzio these buoys guided radio-equipped landing craft to their appointed positions on the beaches. In the English Channel and in the North Sea they marked sunken wrecks. Before D-Day these ultrasonic buoys were laid off the French shore to guide the ships through the enemy minefields without arousing the suspicion of a highly-nervous enemy.

The principle of sending out USW pulses and measuring the reflection time is used in industry for finding flaws in metal blocks or the level of a liquid in a metal tank.

A liquid or solid traversed by an ultrasonic wave system acts on light like a diffraction grating, the lines of compression being lines of greater density. If USW are thus applied to anisotropic crystals, they give rise to interference images which reveal at one glance the elastic symmetries of the crystal. Bergmann who shows some beautiful pictures of this type in his book on *Ultrasonics* emphasizes that one and the same sample yields at once a complete system of all the constants in a way not obtainable with any previous method.

The diffraction spectra produced by USW are also used in England by the Scophony system of television.

The extreme shortness of the ultrasonic waves down to the order of 0.00055 mm., that of visible light, makes them handy as a measuring device, while the long, audible sound waves are unfit for laboratory purposes. Instruments applying USW can be used as saccharimeters. They are also used to determine the velocity of sound in different substances; which in its turn reveals many physico-chemical characteristics of the medium, such as compressibility, chemical structure, concentration, specific heat. In soil analysis, frequent shaking and centrifuging is required to disperse the colloids from the soil grains. But treatment with USW disperses them in a few minutes.

Immiscible liquids such as oil/water or mercury/water are

transformed by USW into very stable emulsions. Colloidal systems with any desired size of particles can be obtained by USW radiation, especially in combination with electrolysis. Nitrogen can be dispersed in steel for hardening purposes, nickel molecules are loosened up, facilitating magnetic reversal – but to what extent such methods are applied in industry it is difficult to ascertain. The photographic industry, it seems, makes extensive use of this property of USW to produce fine and homogeneous emulsions.

While USW energetically disperse solids and liquids in water, they have the contrary effect on systems called aerosols, such as fog, mist, dust, smoke – solids or liquids finely dispersed in air. Such substances when irradiated by USW are instantaneously clotted together and sink down leaving the air immaculately clean. Why this opposite effect? The answer is that a startlingly revolutionary process called *Cavitation* occurs in water but cannot occur in a gas. Cavitation so disrupts a liquid that even if it was formerly gas-free, it is then interspersed with gas bubbles. When a cavity collapses, pressures of thousands of atmospheres may be developed, and high kinetic energies concentrated at very small spots create devastating mechanical effects. Cavitation is produced by high speed propellers and causes heavy erosions in armour plates, a headache for naval engineers.

But cavitation is also produced by USW during the expansion phase. It is not the formation of a cavity, but its vehement collapse which causes such turbulent processes as emulsification. It also brings oxygen into a reactive state and various chemical reactions, e.g. the formation of hydrogen peroxide, may thus be indirectly stimulated by USW. Liquids often emit visible light during cavitation. Obviously some kind of exciting or electrifying action must go on in those cavities. If cavitation is prevented, which can be done either by working in a vacuum or under high external pressure, USW neither liquefy gels nor emulsify oils, but in the emulsification of water and mercury, cavitation has no part.

Liquids with a low boiling point can be made to distil at room temperature when radiated with USW *in vacuo:* as the liquid boils in the cavities, the gas bubbles quickly combine to larger bubbles and climb up.

If small living organisms are exposed to USW, they are mostly torn to pieces or burnt or otherwise destroyed. But what really happens is not yet quite clear. In some cases, cavitation has been observed in the medium, in others it has not. Living beings exposed at the same time to violent compressions and rarefactions of the medium, cannot endure the enormous tension. But if they are small enough to be collected in the nodes of standing wave patterns, they may rest there happily and unharmed – as long as no cavitation occurs.

If a liquid which swarms with bacteria is exposed to sound waves, the cells explode quickly and the antigens, otherwise difficult to extract, are liberated.

In Japan, a verminous parasite used to ruin billions of silkworm cocoons annually. If the affected cocoons are immersed in water and bombarded with USW for 3 minutes, the parasites withdraw into the body of the worm and quickly die there from suffocation.

USW are further reported to deprive yeast cells of their power of multiplication, luminous bacteria of their luminosity, pathogenic bacteria of their virulence, to sterilize milk and to give milk a 'soft curd character'.

Everybody would expect that powerful rays which can be focussed would be valuable medical assistants, and indeed the literature abounds with pious hopes in this direction. But the only paper I have discovered that tells of real cures is one by Pohlman, Richter and Parow (*Medizinische Wochenschrift*, 1939) who successfully treated cases of Sciatica and Plexus Neuralgia.*

While the production and exploitation of USW is a new adventure for us human beings, animals have used them since

* More clinical experiments will be needed to know if this treatment has real value. *Ed.*

time immemorial. The hearing apparatus of many animals is obviously sensitive to these vibrations. When Galton blew his high frequency whistle, spectators who heard nothing, but saw his dog obey the call, suspected occult doings. Ultrasonic utterances have been studied in grasshoppers, but the best examined case so far is that of the bats. When they fly through dark woods or long tortuous caves, they do just what Langevin did first in 1917, namely send out pulses of USW and then decide from the time and direction of the echo where there is an object lurking in the dark.

The Americans Pierce, Griffin and Galambos made bats fly through barriers of parallel wires in complete darkness and recorded the hits or misses. When only the mouth was covered, the bats were as unaware of the wire as with plugged ears. When only one ear was covered, they lost their pluck. They need both ears for localisation, just as we do.

Bats emit three distinctly different types of sound: (1) a shrill audible cry (7,000 cycles per second, lasting $\frac{1}{4}$-second or less) not contributing to obstacle avoidance; (2) an ultrasonic cry (ranging from 30-70 kilocycles, lasting 0.15 seconds, unfailingly accompanied by (3) a feeble click which, when the bat is in flight, is repeated so quickly as to be noticed as a buzz.

Remarkable is the way bats vary their ultrasonic utterances according to where they are and what they are doing. They utter less than 10 ultrasonic cries per second, when sitting on the wall and preparing for the flight; 20-30 when flying through unobstructed space; 50-60 when approaching the obstacle; then there is a sudden drop to 30, and when this drop happens, you know they have got through unscathed. If it does not happen, this is a bad sign.

The audible and the inaudible cries can be emitted at once, but as the audible is never heard during flight, the inaudible obviously is no overtone. Each bat has a 'personal' voice of its own, an individual combination of frequencies and relative intensities. This 'significant cry' comes from

bats preparing to fly or to alight, from caged bats seeking escape and cave bats awakened from sleep.

How do the bats produce all these sounds? They are certain to come out of the mouth, and they are probably produced in the larynx. No explanation was found for the independence of the audible and ultrasonic tones or for the extraordinarily high rate of emission of the latter.

Anti-Vitamins

PROFESSOR JOHN YUDKIN

MANY substances are now known which antagonise the action of certain of the vitamins. Such substances may, in an animal, produce the signs of vitamin deficiency, even though the diet contains what is normally an adequate amount of the vitamin. In so far, therefore, as these 'anti-vitamins' may occur in natural foodstuffs, they are clearly of importance in the field of practical dietetics. But a closer study of them, and of the history of their discovery, shows that they have a far wider theoretical and practical interest. An understanding of them is, for example, necessary for those who are concerned in the present intensive search for new drugs for the treatment of human disease.

Most of the anti-vitamins belong to the group of 'metabolic analogues' or competitive inhibitors. To understand how this type of substance functions we shall have to go back a long way through quite unexpected paths. We might begin with Ehrlich, who, nearly 50 years ago, developed his 'side-chain' theory to account for the phenomenon of specific immunity.

When a person develops an immunity to a bacterial infection like typhoid fever, his blood becomes capable of reacting with the typhoid bacteria, and making them 'agglutinate', or clump together. What has happened is that, during the infection, the typhoid bacteria (the antigen) made the infected patient produce in his own blood a specific antibody so that whenever the blood again comes into contact with typhoid bacteria, the antibody reacts with the bacteria, which then agglutinate and so are rendered harmless.

According to Ehrlich's theory, the reaction between the antibody developed in the blood and the antigen of the

bacteria occurs by a union between the two; the fact that antigens for different bacteria combine with different and very specific antibodies in the host is supposed to be due to the two substances being of such a structure that the one just fits into the other (Fig. 3). No other antibody will combine with this antigen because no other will have a structure which fits the appropriate group or 'side-chain' of the antigen.

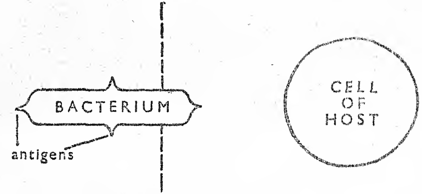


Figure 3a—Bacteria entering body of host.

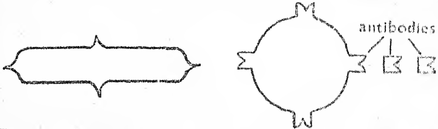


Figure 3b—Bacterial antigens stimulate cells of host to produce antibodies, which circulate in the bloodstream.

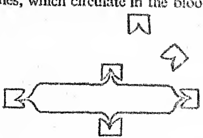


Figure 3c—Further bacterial invasion leads to combination of host antibodies with bacterial antigens, and bacteria are agglutinated.

Specificity of Enzymes

A similar idea was developed by biochemists to explain how it is that enzymes, like antibodies, are very 'fussy' about the exact constitution of the substance (substrate) with which they react. For example, the pancreas makes several enzymes, which digest proteins, carbohydrates and fats. But the enzyme which digests proteins will not digest fats or carbohydrates. More than this, an enzyme which will act upon one sort of carbohydrate will not attack another. One enzyme will act on cane sugar, but not on malt sugar; although they are similar sugars, there are certain chemical differences between them which make only the one able to attach itself to the enzyme. The simile which is commonly used to explain this extraordinary specificity of enzyme action is that of the 'lock and key'. The atoms and bonds which go to make up a chemical substance confer upon it a characteristic structure just as the grooves and notches confer a characteristic structure to a key. And just as the key will only fit a lock for which it is made, so a chemical substance will only fit its appropriate enzyme. Unless it fits, the enzyme cannot act upon it.

Enzyme Inhibition

With this sort of picture in mind, many workers have been carrying out investigations on the mechanism of enzyme reaction. One of the most active laboratories in this field is at Cambridge, where Dr Stephenson and her colleagues have been studying the enzymes of bacteria for more than 20 years. In one of these studies, it was found by Dr Quastel that certain substances interfered with the action of an enzyme upon its own specific substrate. The action which he was studying was the oxidation of succinic acid by the enzyme succinic oxidase, and the substance which interfered was malonic acid. One curious thing about the interference was that the degree of interference did not depend so much on the absolute amount of malonic acid that was present, as on the relative amount of malonic to succinic acid. When

malonic acid was added to the active enzyme, the rate of oxidation of succinic acid was reduced, but it was considerably restored if more succinic acid was added and again inhibited if more malonic acid was added.

$$\begin{array}{l} CH_2\cdot COOH \\ | \\ CH_2\cdot COOH \end{array} \qquad\qquad \begin{array}{l} CH_2\cdot COOH \\ | \\ COOH \end{array}$$

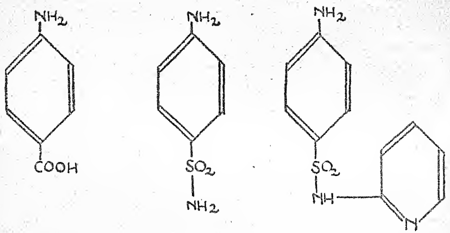
Succinic acid *Malonic acid*

Figure 4

It seemed as if there was a competition between these two substances. Because of their similar structure, either could apparently combine with the enzyme, although only the succinic acid could be acted upon (Fig. 4). Since there was only a limited amount of enzyme, the combination of malonic acid with the enzyme meant that there was less of the enzyme available to combine with the succinic acid. One can picture the molecules jostling each other for places on the enzyme. And one can see how it is that the amount of oxidation which occurs depends on the relative amounts of the two competing types of molecules.

Sulpha Drugs

A similar explanation was advanced by Dr Woods, who had also been a pupil of Dr Stephenson, to account for the action of the sulphonamide type of drug on bacteria. Bacteria may, like animals, require particular nutrients – vitamins – for their growth, and one of these, required by several species of bacteria, is a substance called para-aminobenzoic acid. Dr Woods was struck by the chemical resemblance of several of the sulpha drugs to this substance, and suggested that these drugs act by competitive inhibition (Fig. 5). That is, they get in the way of the vitamin wherever it is in the bacteria that it carries out its function. This theory, that the sulpha drugs act as anti-vitamins for certain species of bacteria, is supported by the fact that bacteria prevented from growing by the addition to their culture medium of



A. B. C.

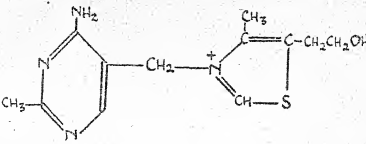
A *para-aminobenzoic acid.* B *sulphanilamide.* C *sulphapyridine.*
Figure 5

one of the sulpha drugs, are able to grow again if para-aminobenzoic acid is added.

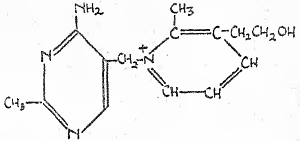
Vitamins and their Competitors

Since that time, a number of substances have been found which act as anti-vitamins in animals. Many of them are substances which have been specially synthesised so as to be chemically similar to vitamins; others have been found to occur in nature. An interesting feature of the synthetic substances is that, until they are tested, one does not know whether they act as vitamins or as anti-vitamins. A substance acts as a vitamin if its structure is sufficiently similar for it to take part in all the essential functions of the cell in which the original vitamin is involved. On the other hand, it acts as an anti-vitamin if its structure is sufficiently similar for it to attach itself to the appropriate points of action of the vitamin, but not enough for it to fulfil its functions: in this way it simply displaces the vitamin and may produce deficiency disease in the animal.

One of the first examples of this which was discovered, is a substance – pyrithiamine – which acts antagonistically to vitamin-B_1 (thiamine). A glance at the formulae shows



Vitamin B_1 (thiamine).

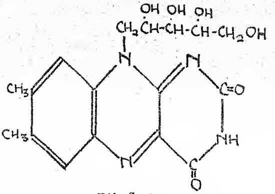


Pyrithiamine.

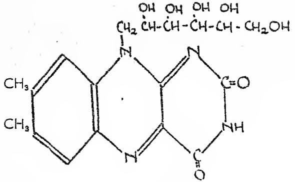
Figure 6

how closely similar are the chemical structures of these two substances (Fig. 6). Pyrithiamine fed to mice rapidly produces deficiency of vitamin-B_1 – produces it, in fact, more quickly and more severely than does feeding the mice on a diet deficient in the vitamin. If the amount of vitamin-B_1 in the diet is increased, no deficiency is produced; if more pyrithiamine is added, deficiency again occurs and again may be avoided by increasing the dietary supply of the vitamin still further. In other words, this anti-vitamin acts as a competitive inhibitor just like the sulpha drugs in bacteria.

Many similar substances have been discovered or prepared and we now have anti-vitamins for a great many of the vitamins. Many of them are known to act only on bacteria but quite a number can be shown to produce their effect in animals (e.g. Fig. 7). It would be a formidable task to enumerate all of these, so we must be content with ciing some of the more interesting examples.



Riboflavin.



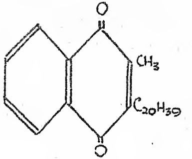
Galactoflavin.

Figure 7

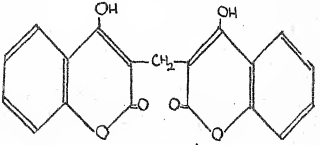
The Sweet-Clover Disease

One such example concerns a naturally occurring anti-vitamin which has considerable practical importance. Some 20 years ago a disease was observed in the prairies of Canada and the Western States of America in which the cattle suffered from hæmorrhages severe enough to cause many deaths. A relatively small operation such as castration, or even a scratch from a fence, often led to bleeding which sometimes could not be stopped. At first, this disease was thought to be due to some sort of infection, but intensive search failed to reveal any possible disease-producing organism. After a time it was noticed that the disease seemed to be associated with the consumption by the cattle of spoiled sweet clover, and animals could often be cured if

this food was removed from their diet. Attempts were then made to extract what was apparently a toxic material from the spoiled clover, and after a great deal of difficult chemical work, a substance was isolated which seemed to be the cause of the disease. This substance, dicoumarol, was found to cause bleeding in experimental animals because of an interference with the clotting power of the blood. The effects produced by feeding dicoumarol were exactly similar to those produced by a deficiency of vitamin-K, and administration of vitamin-K overcame the toxic effects of dicoumarol (Fig. 8). The spoiled sweet clover, then, produces its



Vitamin K.



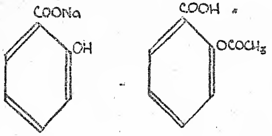
Dicoumarol.

Figure 8

effect because it contains dicoumarol, which leads to a deficiency of vitamin-K in the cattle owing to its action as a competitive inhibitor of the vitamin.

There are two further points of interest in connection with this. One is that dicoumarol is now being used in medicine in conditions where it is desirable deliberately to

decrease the clotting power of the blood; amongst such conditions are coronary thrombosis and thrombophlebitis. The second interesting point is the possible anti-vitamin-K activity of salicylates or aspirin. Very large doses of these drugs are given in some conditions, notably rheumatic fever, and it has occasionally been noticed that this is followed by a tendency for bleeding from the alimentary canal. If such effects occur nowadays, they are treated with vitamin K. The chemical structure of salicylates and aspirin shows that they might well be expected to act antagonistically to vitamin-K (Fig. 9).



Sodium salicylate. *Aspirin.*

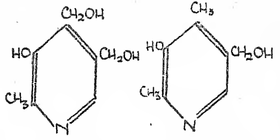
Figure 9

Apart from the naturally occurring dicoumarol, other antagonists for vitamin-K have been synthesised in the laboratory: one of these is a substance called α-tocopherol quinone. This is similar to vitamin-E (α-tocopherol) but it also resembles vitamin-K. In pregnant mice, it leads to a cessation of pregnancy, just as does a deficiency of vitamin-E. Curiously, however, its harmful effects are not overcome by vitamin-E but they are overcome by vitamin-K. So here we have a substance chemically similar to two vitamins, which causes a deficiency of one vitamin, but whose effects are only counteracted by the other.

Vitamin or Anti-Vitamin?

It was mentioned earlier that a substance made so as to resemble the chemical structure of a vitamin might not necessarily act as an anti-vitamin, but might actually be

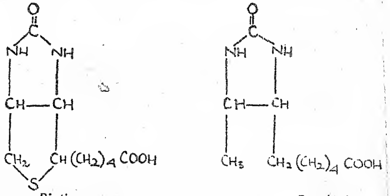
whether the new substance fits into the appropriate
in the living cells well enough for it to take over the fur
of the vitamin, or only well enough for it to get in tl
of the vitamin. In some instances a chemical substanc
be able to act as a vitamin for one species while it is aı
vitamin for another species. Here are two examples
first concerns vitamin-B_6 or pyridoxine, one of the vit
that are sometimes classed together in the vitamin-B_2
plex. One derivative of this, desoxypyridoxine, can be
instead of pyridoxine for the growth of certain bac
whereas in the chick it acts as an anti-vitamin and c



Pyridoxine. *Desoxypyridoxine.*

Figure 10

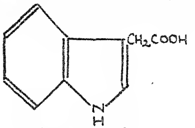
deficiency of pyridoxine (Fig. 10). Another derivative
vitamin for some plants, for example tomatoes, and
anti-vitamin for certain fungi. The second example conc



Biotin. *Desthiobiotin.*

Figure 11

So the development of pellagra depends on whether there is a deficiency of both of these substances in the diet. Maize is known to be very deficient in tryptophane as well as fairly deficient in nicotinic acid, whereas other diets, containing for example rice, even though they may contain less nicotinic acid, have enough tryptophane to be able to make up for this. But this does not seem to be the whole story, for a diet containing just enough nicotinic acid and tryptophane to prevent the development of pellagra, will produce pellagra if maize or maize products are added. It seems that, after all, the old 'toxic' theory of the causation of pellagra must have had at least some truth in it. Although we are not yet certain what this toxic substance is, it is very likely to be an anti-vitamin for nicotinic acid, and in fact recent work suggests that it is indoleacetic acid (Fig. 14).

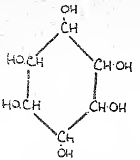


Indoleacetic acid.

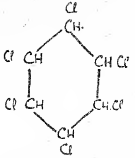
Figure 14

Anti-Vitamin as Insecticide

Nicotinic acid is one more of the group of vitamins in the vitamin-B_2 complex. Still another is inositol. Although this has not been shown to be of much importance in the higher animals, it is needed for the growth of some yeasts and, it would seem, for some insects. And it is of interest in the same sort of way that para-amino benzoic acid is of interest. We noticed that the sulpha drugs act by 'starving' bacteria of this substance, which, for them, is an essential nutrient. Similarly, a substance is known which competes for inositol, so that yeast will not grow in its presence unless a great deal more inositol is added. You may not recognise this substance by its name of γ-hexachlorocyclohexane, but 666 or gam-



Inositol.



Gammexane.

Figure 15

mexane no doubt strikes a more familiar note (Fig. 15). It is a powerful insecticide and there is good reason to believe that it works as an anti-vitamin, starving insects of inositol so that they die of a vitamin deficiency disease.

Bacterial Anti-Vitamins

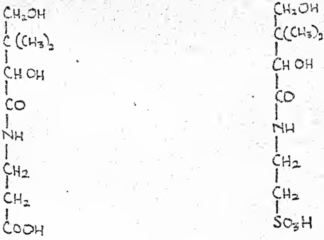
During the last few years, increasing evidence has accumulated that some vitamins are synthesised by bacteria in the alimentary canal of many animals. Appreciable amounts may be absorbed into the blood stream of the animal and decrease the dependence of the animal upon dietary sources of these vitamins. A curious result of this arises from the administration of anti-bacterial drugs, such as the sulpha drugs by mouth. This may cause a considerable decrease in the number of certain species of bacteria in the alimentary canal and consequently a decreased synthesis of vitamins. As a result, the amount of these vitamins in the diet, which was adequate when supplemented by the vitamins synthesised by the bacteria, may now not be adequate, and vitamin deficiency may be induced. This has been clearly demonstrated in experimental animals given sulpha drugs. In some instances, such as vitamin-K in rats, the amount of a vitamin synthesised by the alimentary bacteria makes it difficult to obtain deficient animals by dietary means alone, whereas the simultaneous administration of sulpha drugs

some of the members of the vitamin-B_2 complex (biotin, folic acid and pantothenic acid) can rapidly be induced in rats by treatment with these substances. We have, then, the interesting fact that they exert their effect by rendering the bacteria deficient in a vitamin, and in turn the death of the bacteria may render their host deficient in one or more vitamins.

There has also been some suggestion lately that penicillin, as well as the sulpha drugs, may have a similar effect. Patients given penicillin by mouth seem sometimes to develop mild pellagra, and this would be due to the decreased formation and absorption of nicotinic acid, because of the killing of alimentary bacteria by the penicillin.

Quite apart from this indirect production of deficiency in the host the action of anti-vitamins on the bacteria is, of course, important in itself, as we have seen in the case of the sulpha drugs. The use of these chemotherapeutic drugs in medicine began some years before their mode of action was known, but now that we have this knowledge, a great impetus has been given to the search for new drugs. Large numbers of anti-vitamins have been synthesised in the hope that they will prevent the growth of harmful bacteria. It is, of course, necessary that these substances shall exert their effect to a far greater extent on the bacteria than on the infected host.

So far, it must be admitted that the search has not provided any spectacular results. However, some interesting developments have occurred and it seems likely that further work will provide something really worth while. One of the most promising lines of research is concerned with substances which antagonise pantothenic acid, still another vitamin of the B_2 complex. This is necessary for the growth of such bacteria as the streptococcus and the pneumococcus, the organisms which produce among other conditions blood poisoning and pneumonia. The most effective antagonist to pantothenic acid is pantoyl-taurine (Fig. 16). This



Pantothenic acid. *Pantoyl-taurine.*

Figure 16

prevents the growth of several species of bacteria in laboratory cultures and will also prevent infection with these organisms in rats. Unfortunately, it is necessary to give far larger amounts of pantoyltaurine than could possibly be used in medicine, but it is likely that other derivatives of pantothenic acid may be more successful.

There is some evidence that the drugs which are used in the prevention and treatment of malaria – quinine, mepacrine, paludrine, and others – may act upon the malarial parasite in some such way as do the anti-vitamins. If this is confirmed, we shall have a new method of approach in the preparation of anti-malarial drugs. It has also been shown that anti-vitamins for pantothenic acid can cure experimental malaria in chicks. Again, this work is as yet not sufficiently developed to be applied in human malaria because it is necessary to use such amounts of the anti-vitamin as to produce deficiency in the chicks as well as in the parasites.

Anti-Vitamins which are not Competitive Inhibitors

So far, we have described substances which are chemically allied to the

mins for a place in the living cells. There are some anti-vitamins, however, which act quite differently, either by combining with the vitamin so that it becomes inactive or by actually destroying the vitamin.

Egg-white contains a substance which has a very strong affinity for biotin. This egg-white substance, avidin, combines with the biotin of the food and the resulting compound cannot be utilised by the animal. Experiments have been done both with laboratory animals and with human beings, and biotin deficiency produced by diets containing large amounts of egg-white. One way of overcoming the effect of avidin is by giving biotin anti-vitamins like the desthiobiotin we have described. These can combine with the avidin and leave enough biotin for the use of the animal. So we have the interesting situation that either avidin in egg-white, or synthetic anti-vitamins like desthiobiotin, will each produce biotin deficiency in an animal, but that both together may lead to normal healthy growth, since they combine with one another and leave the biotin itself free.

There are only a few examples of anti-vitamins which act by destruction of the vitamin. Breeders of silver foxes in the United States of America were much concerned a few years ago by the fact that some of the foxes on their farms lost their appetites, became very weak or even paralysed, and many eventually died. Investigation into the cause of this disease, which threatened serious financial consequences to many of the farmers, showed that it was due to deficiency of vitamin-B_1 (thiamine). It was then shown that this disease was associated with the consumption of raw fish which was often fed in considerable amount to the foxes. The raw fish contains an enzyme, thiaminase, which acts upon and destroys the vitamin in the food. Simple cooking of the fish was sufficient to prevent the disease since, like most enzymes, thiaminase is quite easily destroyed by the heat. A similar enzyme which destroys vitamin-C, is found in green vegetables, and this accounts for the instructions given by the Ministry of Food for the cooking of green vegetables. If

they are put into cold water and gradually heated, especially if they have previously been cut up so that the enzyme and the vitamin in the cells are brought into close contact, quite an appreciable destruction of the vitamin occurs before the heat is sufficient to destroy the enzyme. On the other hand, if vegetables are put straight into boiling water, the enzyme is rapidly destroyed before it has had much time to act upon the vitamin-C.

This short account of anti-vitamins demonstrates three things. In the first place, the nutritionist has been able to make many advances in fundamental knowledge about the way in which vitamins act. He has also been able to produce experimental diseases for detailed study, in animals in which it had previously been difficult or impossible to produce them. He has, that is, a new technique at his disposal for the study of nutrition and, as with all experimental sciences, development of fundamental knowledge cannot proceed faster than the technical methods which are available.

Secondly, we now know that we must look, in our foods, not only for the presence of adequate supplies of vitamins but for the possible existence of substances which antagonise them. It is very unlikely that the anti-vitamins in raw fish or in maize are the only ones which exist, and it is necessary to bear in mind that there may well be others.

Thirdly, we have a completely new approach to the problem of the production of new chemotherapeutic agents whereby we can study the nutritional requirements of disease-producing bacteria, and then attempt to kill them by interfering with their nutrition by anti-vitamins. There is no doubt that, however laborious the search will be, and however numerous the compounds which have to be made, there will be sooner or later a number of effective new drugs which will give still more of that benefit to mankind which penicillin and the sulpha drugs have already given.

Modern Applications of Photography

D. A. SPENCER

USES OF AIR PHOTOGRAPHY

ALL our economists are agreed on one point, namely, that one of the most vital problems confronting the British people – a problem that must be solved if social security is not to remain a pipe-dream and the standard of living is to rise rather than fall – is to bring about a great increase in national efficiency by the raising of national productivity, both in volume and quality. I believe that photography in its many forms will be an indispensable tool in achieving this object.

Unfortunately, man is on the whole intellectually lazy, and it is a sad thought that only under the primitive stimulus of war does he usually muster the collective will and energy to apply available knowledge to achieve his aims in the shortest possible time. The major contributions photography made to victory depended not so much on basically new discoveries in the range of photographic technique as on the effective harnessing on an adequate scale of techniques whose potential value was known in 1939. This thesis is well exemplified by the recent history of air photography.

In 1940 a remarkable organisation was built up in Britain for collecting by air photography information about the day-to-day progress of our enemies' war effort. This organisation – the Photographic Reconnaissance Units and the Central Interpretation Unit – was responsible for obtaining the majority of the intelligence information we received from Occupied Europe after the fall of France.

When the Allies have got sufficiently tired of maintaining occupation armies in Germany it is to be expected that they

will recall how successfully we kept an eye on Germany by the far cheaper and more convenient technique of photographic reconnaissance. In conjunction with a small group of specialists on the ground it is quite capable of ensuring that no major industrial or warlike activity takes place in Germany without our knowledge.

That aerial photographic reconnaissance would be an important source of information was, of course, recognised before the war, but few, even of those intimately concerned, realised before 1941 the remarkable results that could be obtained by a combination of first-class aerial photography with a thorough study of the resulting photographs by experts in many different fields working in close collaboration. The experience which has been gained is capable of direct application to peace-time research. Indeed, much information of interest in this connection is probably potentially available in the many thousands of negatives already made by the Allied air forces, and it is to be hoped that this will eventually become accessible through appropriate centralised libraries.

Interpretation

There are two main types of aerial photograph – the oblique, that is, the pictorial or bird's-eye view made through the side of the aircraft (Plate 23), and the vertical taken through the floor, producing a photograph of the ground as on a plan (Plate 1).

Although to the untrained observer the oblique presents the more familiar view, the scale varies from foreground to background and there is much 'dead' ground in hilly or wooded regions, and vertical photographs were of much greater use to our interpreters.

Such photographs are not pictures in the conventional sense, but rather a mosaic collection of details whose meaning is not immediately obvious. The amount of information which an interpreter can extract is directly proportional to his experience. This in turn is dependent on his full under-

standing of air photographs as a source of information, his knowledge of the subject being studied and his access to a series of photographs of the same area made on earlier occasions. He is immeasurably helped by the fact that the photographs can be viewed stereoscopically; that is, the picture appears to be a visual model in three dimensions. A right and left eye record is necessary for a scene to appear in relief, and the amount of this relief is determined by the distance apart of the two viewpoints. When we examine a scene with our eyes, which are only about a couple of inches apart, all sensation of relief disappears when objects are more than 500 feet away. But the interpreter examines the landscape as though he were a giant with eyes several hundred yards apart, merely by placing in his stereoscope a pair of prints from the series of overlapping records which the detached eye of the flying camera has provided.

Every stereo pair of war-time reconnaissance photographs was studied by specialists in many different fields, supplying its quota of information to each. By 1943, we had compiled what was virtually a photographic Lloyd's Register of enemy shipping, and we had learned to tell the type of cargoes and probable destination of every enemy ship that mattered. We followed every important aspect of German industrial activity and knew with remarkable accuracy the month-by-month output of all important factories. We watched Germany's progress in research on radar and atomic bombs. Photographic intelligence revealed enough information about the development of the flying bomb in time for us to make such preparations as were possible to reduce the attacks from a major disaster to a nuisance of no effect on the outcome of the war. Meanwhile, we were accumulating, *via* the air camera, essential information on every aspect of the Normandy beaches and landscape which would facilitate invasion.

Future Applications

We have accumulated, then, considerable experience with a powerful tool of research, and it remains for us to adapt it

to the sane requirements of peace. A complete understanding of the various ways in which this is being done would require knowledge of the technique of photography which I must not assume. Accordingly, I shall have to ask the reader to accept some of my statements as to what is possible on trust, though I will illustrate them as well as I can by photographs showing the techniques in action. The fact that with one blink of its glass eye an air camera can make a detailed record of the countryside which it would take an artist months to draw is of course well known. What is not so obvious is the enormous importance of the fact that the record is an exact one from which sizes and distances can be accurately deduced. Much of the value of air photography in war and peace is due to the many ways in which such measurements can be turned to advantage. The most familiar, because the most obvious, is the use of air photographs in survey.

Surveying

The speed and convenience of aerial mapping has long been admitted, and for inaccessible or difficult country such as the jungles and swamps of Africa, aerial mapping is obviously invaluable, but its pre-war accuracy left something to be desired. As a result of war experience, it can safely be claimed that any required degree of accuracy is now attainable. In some cases, this accuracy exceeds that of conventional ground surveying, while the improved techniques available are resulting in appreciable saving in cost.

The usual procedure is for the aircraft to fly backwards and forwards over the territory to be mapped, taking vertical photographs on calibrated cameras – the dials of instruments recording height, tilt, etc., being photographed simultaneously along one edge of the film. The cameras employed are set to take photographs automatically at predetermined intervals, which are such that there is an overlap of about 60% between neighbouring records. This is necessary in order to provide the stereo records on which most mapping

systems depend. Moreover, to ensure that gaps are not left in the record as a result of navigational errors, the parallel lines of flight are close enough together to ensure a generous overlap between each string of records. This lateral 'insurance' overlap, which is wasteful in time and material, is not necessary in the most modern air survey technique in which the navigation of the aircraft and the operation of the survey cameras is by radar control from a ground station. The pilot's responsibility is reduced to keeping his aircraft flying at the specified height along the radar beam, the camera operating at the correct intervals without his intervention. This technique also makes it possible for the ground station to direct the aircraft to any predetermined point on the terrain and then operate the camera as many times as are necessary to fill in any gap in the records of an earlier flight, due, for example, to the presence of an isolated cloud below the aircraft. As a result, two or three photographs are all that are necessary to cover such gaps, as against the many hundreds of exposures which are required to ensure proper coverage when navigation and photography are controlled by the aircraft crew.

The resulting photographs are built up into a mosaic record of the whole territory – a pictorial map adequate for many purposes and containing information from which dimensionally accurate maps can be prepared. The aerial camera in effect brings the territory to be mapped to the surveyor's laboratory for measurement.

It follows from the fact that by suitable techniques a contoured map of the countryside can be prepared that dimensioned plans of buildings can be derived from such photographs. From such plans accurately-scaled models can be prepared and rendered remarkably lifelike by sensitising their surface with photographic emulsion and then projection printing on to them from a negative of the target. The clockwork precision of the successful attack on St. Nazaire in March, 1942, owed much to the photographically-produced model of the port which was made during the

previous year. This model was photographed from various angles of approach and in lighting corresponding to that which would prevail at the time of the attack. Thus the participating forces were briefed with photographs of their various objectives which looked as though they had been made at ground level from a distance of a few hundred feet.

The technique of deducing the dimensions of a building from photographs was applied after the 1914-18 war to the problem of reconstructing war-damaged buildings of which dimensioned plans did not exist. Several French churches, for example, were rebuilt from accurately-scaled plans deduced from snapshots. Plate 25 is an illustration from Deneux's *La Métrophotographie appliquée à l'architecture*, a fascinating account of the geometrical methods available for carrying out the calculations.

In America at the moment, air photographic surveys are being carried out over all existing and several projected highways. It has been shown that it is possible to calculate from the photographs the cubic footage of earth to be removed or the concrete required at particular parts of the route far more simply and accurately than by ground methods, and the economy which has resulted is already regarded as having paid for the cost of the survey.

Air photographs made primarily for survey purposes will record a mass of data of interest to all those concerned with such economic aspects as land utilisation, agriculture, mining, town planning, electricity, water and transport services (see e.g. Plates 1, 18 and 17). In many cases, however, special flights at particular seasons and times of the day will be necessary if air photography is to contribute fully to developments in other fields, of which the following are representative examples.

Archæology

Archæologists were made aware through the pioneer work of Crawford, Kieller and Insall of the value of the point of view given by the aeroplane, and many sites of archæological

importance have been discovered by its use. Slight banks, grass-covered foundations or depressions in the earth's surface which are all that remain of early earthworks, may pass unnoticed on the ground, but acquire significance when viewed from such a distance that any shadow cast forms a geometrical pattern which is obviously man-made. Such shadow sites will be most clearly revealed when the sun is low and in the right direction to cast a significant shadow. However, the most fascinating – because quite unsuspected – phenomenon which air photography revealed was that growing vegetation is affected as regards its average size and colour by the previous history of the soil. For example, if a ditch has been dug on a chalk down and afterwards ploughed flat and sown with corn, for ever afterwards the silt filling that ditch differs from the ancient, never disturbed soil. The more moist or more fertile silt promotes the growth and deepens the colour of the crop and hence in the spring the ancient excavation is annually outlined by a patch of darker green corn (Plates 36 and 37).

Ancient roadways and wall foundations are sometimes revealed by the reverse effect. The shallow stony soil of the site results in a relatively poorer growth of the crop, or during a drought leads to more rapid 'parching' of vegetation on the site (Plate 35).

A remarkable example is the ground plan of Caistor, near Norwich (Venta Icenorum). The roads, streets, houses, temples and market places of this Roman town are all clearly revealed in an air photograph made during the drought of 1928. It will be a matter of chance whether such crop markings will record on air photographs made for other purposes, and for maximum results specially arranged flights under the direction of an archæologist must be made over areas, known to be of interest, at appropriate seasons and times. A recent series of flights planned in this way, in two days' flying time, added more to our knowledge of Roman Britain than the previous two centuries of archæological research!

Ecology

Ecologists, concerned as they are with what might be termed biological geography, have already used air photographic surveys of South America to provide data on the density and distribution of population, distribution of arable land, natural barriers and natural avenues of travel, sources of power, fuel and water, land utilisation, facilities for transport and the influence of topography on the location of roads and towns. Such investigations have a close relationship to the sort of studies we have made of Germany during the war, while the methods so successfully applied to ferreting out the activities of our human enemies are directly applicable to non-human pests – animal and vegetable. The control of such disease-carrying insects as the mosquito and the tsetse fly by spraying from the air is now familiar. More indirect methods of control may well emerge from studies of bird migration and population on inaccessible islands made by means of the air camera. As a minimum, surveys of this type should be a very convenient method of checking the efficiency of our attacks on such pests as the boll weevil or the Colorado beetle. Meanwhile, the advance of bracken over grassland, and of prickly pear in Australia, and the distribution and effect on each other of plant communities (woodlands, jungles, prairies) are already being effectively studied by air photography.

Colour Filter Techniques

So far I have dealt with ordinary black and white photographs of the type one can make with the photographic films used for amateur snapshots, but made through a medium yellow filter. This absorbs ultra-violet radiation and deep blue light which, being scattered by haze, would otherwise reduce the clarity of long-distance photographs. Full advantage has yet to be taken of the fact that, by the use of specially sensitised films and suitable colour filters, the camera record can be made to emphasise detail and differentiate between various features of the landscape in a

manner quite impossible to the human eye. Forestry provides a number of simple illustrations. Thus, a recent air survey of the forests of Southern Sweden was made at a season when the beech foliage contrasted with that of other trees – enabling the beechwood resources to be assessed. This is a simple case, however, for, to the eye and the ordinary photographic film, beech foliage is noticeably lighter than the general run of leaves.

By employing over the camera lens a filter which transmits only the particular part of the spectrum reflected most freely by the foliage being studied, it is possible to exaggerate in the photograph subtle colour differences which would be undetectable on an ordinary photograph.

An extreme example of this technique is the use of films made sensitive to invisible infra-red radiation. Infra-red photographs differentiate coniferous trees very strongly from deciduous – the latter recording as though their foliage was white (Plate 18).

An interesting war-time application of such colour filter techniques was the determination of the depths of off-shore water along enemy coast lines.* If a beach is photographed vertically from the air a fair amount of underwater detail is recorded. This means that we are photographing the sea-bed through the overlying water. Now red light is more rapidly absorbed than green light during passage through greenish sea water. If therefore we take two photographs – one through a green filter and one through a red filter – the relative blackening on the two photographs which is determined by the amount of light reaching the film will be greater in the case of the green filter photograph and the magnitude of the difference will depend on the thickness of the overlying water. By careful measurement of these relative blacknesses it is therefore possible to calculate the actual depth of the water down to depths of 40 feet. Such information was invaluable in planning landings on enemy coasts and has

* Devised by the Army Air Photography Research Branch at Larkhill.

already found one peace-time application in oceanography.

Marine biologists are using it for making surveys of animal communities such as oyster beds and seaweed concentrations (for instance, plates 4 and 5). In its present form it has potential value in the preparation of navigation charts, control of pollution, erosion, and the study of the effect of currents and tides on the formation and movements of sand bars. When sufficiently refined, it has been suggested that the method might even be capable of distinguishing between the differing bodies of sea water whose movements determine the movements of fish shoals. The shoals themselves could almost certainly be detected by appropriate forms of reconnaissance photography – an innovation which would have obvious economic importance.

Forestry

These, however, are possible future applications of colour-filter techniques where the records must be made under properly controlled conditions if they are to prove of real worth, and, as I have already indicated, their present use is mainly in forestry studies. Here, even qualitative techniques have already proved of real value. Thus Canadian foresters, from aerial photographic surveys of forest land, have obtained, in addition to such obvious data as the types and density of trees, details of the composition, age and structure which are invaluable in forest control. From the photographs, type maps can be prepared which speed up, simplify and cheapen the operations of forest management. By measurements on stereoscopic pairs of photographs (of the type of plate 19) the height of the timber can be determined by simple instruments. Air photographs are also used in fire control, planning, evaluation of damage by insects, location of property lines, relocation of Canadian highways and the planning of new ones.

It is frequently suggested that colour photography from the air would simplify the task of interpreting such photographs, and already it is known that in some cases useful

information not obtainable from black and white photographs can be recorded on colour film. Insufficient experiments have so far been made, however, to draw any but the most general conclusions.

An aerial colour photograph is easier to interpret by the unskilled, but it is possible that only in certain special cases will it be of important assistance to the skilled interpreter.

During the war a limited amount of 'Aero Reversal Kodacolor' was used by the British and American Air Forces. This was an integral tripack film which yielded subtractive colour transparencies built up from inseparable yellow, magenta and blue-green dye images (see article on Colour Photography in *Science News* 3). Its main application was for such specialised purposes as recording the coloured identification pattern of the target indicator flares dropped by the Pathfinders during night raids and the recording of underwater obstacles near landing beaches in the Pacific.

In a modified form of this film one of the sensitive layers consisted of an infra-red emulsion and the three layers were processed in colours which were not necessarily complementary to their colour sensitivity – as is required for a 'natural' colour rendering. In consequence, green grass, for example, might appear magenta in the colour transparency and features in the landscape which in a normal colour photograph might escape detection could often be clearly differentiated in this 'camouflage detection' film. Such material has potential peace-time applications in forestry, but more objective research is required to evaluate statistically the relative advantages of such specialised forms and natural colour as against black and white air photography, for it is easier than might be thought to be the case, for a skilled interpreter to distinguish between different types of vegetation in black and white air photographs.

Geology

In some regions, vegetation is zoned with respect to eleva-

tion, inclination of slopes, proximity of water and rock outcrops, and hence provides a guide to the interpretation of topographic features, some of which – such as the site of old beaches – are obscure on the ground.

Changes in vegetation over a period of time are often associated with important topographic processes, and as the surveys spread to such vegetation types as sphagnum bog and submerged seaweed beds, they impinge on the interests of geologists, for they yield indirect data on such problems as the silting of estuaries, coast erosion and other factors controlling the development of scenery.

The geologist is, in any event, already aware of the value of air photography in simplifying his studies of geological structure and land forms. Thus, the size, shape, distribution and evolution of complex sand dunes is much easier to assess from the air. Air photographs made for such purposes will in turn facilitate the work of prospectors for mineral deposits, and the mining engineer (see e.g. plates 22 and 24). In Canada, for example, the information on the distribution of rock formations furnished by the early geologists was mostly confined to the main water routes and did not help in the case of wide areas distant from the principal rivers. It is estimated that only 11% of Canada has so far been adequately mapped from this point of view, and that without the use of air photography it would take 200 years to complete the task at the present rate of progress. However, the Canadians are now going all out on an air survey programme, and during 1946 a basic photographic coverage of about half-a-million square miles was obtained – about one-seventh of the total area. For 1947 the target is another three-quarters of a million square miles. Already this work has paid a dividend in the discovery from the photographs of rich tantalite deposits.

Soil Erosion

One of the earliest and most characteristic features of the growth of a civilisation is the change which is imposed on

the vegetation of the countryside. Where Nature would have a forest – or, as in the case of the Nile Valley, a desert – man makes fields, and so on. When, as in England, the country is small and the civilisation old, one finds that the landscape is eventually almost entirely man-made. With increasing facilities for making such modifications which the twentieth century has placed in his hands, man runs grave risks of upsetting the balance of Nature to his own detriment – as when he creates huge deserts in America by unwise deforestation. The new deserts in turn facilitate the production of disastrous floods which, among other things, may lead to the transfer of alluvial soil to inconvenient regions.

Accordingly, extensive development of land by empirical methods will sooner or later have to give way to controlled development based on a study of conditions which can conveniently be made from the air. Since the natural vegetation over any particular region is a product of the various geological and climatic attributes of that region, its study before any development is planned can lead to a rational exploitation of virgin land and appropriate modifications to our treatment of land which is being misused.

Already over 50% of the U.S.A. has been photographed from the air to enable the Soil Conservation Service of Washington, D.C., to compile an inventory of the physical land factors involved in soil erosion. These photographs (Plate 21) are used to determine soil type, land slope, gradient, present use and degree of erosion. The records not only provide a factual bird's-eye view of the land and its present condition, but will be invaluable in future years as a basis for comparing land conditions from time to time and for following trends in land use. The acreage of crops and other vegetation can be determined very rapidly and economically by colouring the photographic prints according to the crop, cutting up the prints and weighing the collection of various-shaped pieces of any one colour. The area can be determined from this weight with an accuracy of 1 in 1,000. Such

photographs can also supply a basis for the making of payments to farmers for diverting acreages from soil-depleting to soil-conserving crops, and for carrying out approved soil building practices.

Physics

The photographs we have been considering were all made from aircraft flying at heights of not more than a mile or so, and the physicist is, on the whole, only mildly interested in them for the data they provide on atmospheric haze. The physicist is more interested in the records obtained on photographic plates which have recently been sent into the stratosphere in rockets. He has thus obtained records of cosmic radiation and the sun's spectrum made above the absorbing blanket of the atmosphere. The man in the street is more impressed when automatic cameras installed in such rockets primarily for other purposes bring back from 100 miles up photographs of the earth's surface which demonstrate conclusively that the earth is a ball. However, the data on cosmic radiation will, in the long run, be a far more important contribution to our control over Nature than spectacular confirmations of something known to Galileo.

The Future

Unfortunately, many of the most interesting peace-time applications of air photography have no immediate commercial future, and the problem is therefore how to get such work carried out. The British Ecological Society has taken a first step by circulating to scientific authorities and responsible Government departments a memorandum recommending the establishment of an aerial unit for scientific work. Such a unit would form an invaluable focal point for researches in many fields and would be of great potential value in another connection. Photographically speaking, we were very backward in air photographic techniques at the beginning of the recent war. Photography was not highly regarded as a service career and certainly offered few attrac-

tions to the scientifically-trained young minds on which research largely depends. The question is therefore how to keep alive this interest in the minds of intelligent men, who doubt whether the next war will be anything like the last one and who are averse to wasting their creative energy on the devising of techniques which may not be required. The creation of aerial units for scientific work, operating from the principal armed forces' air photographic research establishments would seem a reasonable solution, if any group of investigators faced with a scientific problem which air photographs might help to solve could, through appropriate mechanisms, have access to such units. The ground technicians would then have a worthwhile interest in devising modified equipment and techniques for the solution of many different types of problem.

There would be real satisfaction in being a member of a team whose work involved helping, through an archæological group, to uncover details of our history; helping, under the guidance of physicists, to clear up the mystery of cosmic radiation; fighting with the geologists against soil erosion and with the ecologists against the ravages of pests; and so on. Devising techniques most suitable for each type of investigation would result in the accumulation of experience and a nucleus of the right type of trained research worker and technician. It would follow that, if there is another war, photography from the air will be ready from the word 'go' to play its part in man's next effort at destroying what is left of his civilisation.

SOME APPLICATIONS IN INDUSTRY

Broadly speaking, photography is of value in commerce and industry because it can:

(1) make records which are permanent sources of reference and exact measurement in a variety of convenient forms;

(2) operate efficiently under conditions where the eye is helpless either because the light available is too high

or too low in intensity, because the event is too transient or too protracted to see, or because visible light is not involved at all;

(3) record movement, if necessary in such a way that the time scale is altered;

(4) play a basic part in certain fabrication processes;

(5) facilitate all aspects of training and education.

Records

Let us dismiss with a mention such obvious applications as the choosing of factory sites by aerial survey, the recording of each stage in the erection of buildings and plant and the photographic printing processes – known as blue print and diazotype – by which the plans for such activities are duplicated. A conventional photo-copy of a plan made by these processes is the same size as the original and only minor improvements in the processes themselves have taken place in the last 20 years. Document copying processes in which enlargements or reductions are possible, however, are growing rapidly in importance. In these processes the original is photographed by various forms of specialised camera on to bromide paper, photographic film or plates. In the mere fact that the photographic record can be made smaller than the original we have the subject-matter for a long book, for new applications arise almost daily.

In the Statfile system, engineers' drawings are reduced to $6\frac{1}{2}$ inch by $4\frac{3}{4}$ inch records on non-inflammable film. In this form an enormous bulk of drawings can be filed in a relatively small space and at a standard size. From the negative, copies on paper to any required dimensions can be produced by conventional enlargement. In addition, there are numerous systems for recording documents on 35 mm. or 16 mm. film with correspondingly greater saving of space. These range from primitive adaptations of conventional miniature camera equipment to specially designed fully automatic machines which can be operated by people with no knowledge of photographic technique.

During the war essential information about every member of the armed forces was recorded on 35 mm. film, in the first instance to simplify keeping pay records, etc., up to date. However, the same technique obviously facilitated the sending of information on other subjects from one theatre of war to another. A specialised aspect of this so-called microgram service, namely, the Airgraph scheme – a direct descendant of Dagron's pigeon post from beleaguered Paris – made one advantage of such micro-records obvious to the general public, who received and sent more than 1,000 million Airgraph and V-mail letters during the war. The original letters were photographed on to 16 mm. film for convenience of overseas transport, and bromide print enlargements made at the receiving end for dispatch by surface mail.

The release and saving of valuable storage space, protecting of irreplaceable records against loss by war, accident or theft, and the increased availability are obvious advantages of micro-records, of which banks and big business houses are making growing use. U.S. public documents can now by law be thrown away if miniature film copies exist. One machine tool firm which had nearly half-a-million drawings occupying 1,500 square feet of floor space has now microfiled the lot in two drawers of a letter file. Libraries, which began by storing the contents of newspapers in this way, are now extending the method to their books. All English books in the British Museum written before A.D. 1500 have been recorded in this way, and the Library of Congress offers a service of microfilms or positive enlargements of any part of its ten million volumes. Such reproductions serve the student just as well as the, often irreplaceable, originals. This technique has also been suggested as a means of dealing with the problem of publishing and distributing those scientific papers which are too specialised or transient in interest to justify printing in full in the ordinary scientific journals.

Specialised machines – of which the Recordak is a typical

example – have mechanised the procedure for transforming huge piles of documents into midget records on microfilm to a point where the equipment can take its place side by side with other 'business efficiency' aids such as accounting machines and office duplicators. In the latest model of the Recordak, for example, documents such as cheques need only to be fed into a slot by the operator. When they emerge a few seconds later both sides of the document have been recorded next to each other on 16 mm. film. Many documents are recorded in this way, at a rate of 1,000 per hour if necessary, purely as a safeguard against loss or fraud – for example, the cheques passing through a banker's clearing house or the incoming entries complete with serial number and date in football pool and bookmakers' offices. In such cases systems are available for finding automatically particular records on the negatives. For smaller users combination units are available which both make the microfilm record and project it for reading purposes.

Increasing attention is also being given to mechanising the production of paper prints from these negatives, and war-time developments in high-speed automatic processing are a promising first step in this direction. Thus the U.S. Navy required positive photographic records of the images produced on the fluorescent screen of radar cathode ray tubes in the shortest possible time: the right-hand side of plate 34 shows the kind of picture. The problem was solved by producing a photographic film which could be processed to a positive image in a matter of seconds in a processing machine which applied hot solutions to the film in rapid succession. Each solution was removed in turn by vacuum suction and permanent records of the changing images on the radarscope could be seen twelve seconds after photography.

In America hot-processed motion pictures have already been used experimentally as a source of television 'originals' of news events. The overall time for complete processing and drying a single frame of the 16 mm. used was 45 seconds as

against 40 minutes for the normal procedure, and the processing machine operated at the rate of 8 feet per minute.

The R.A.F. asked for a photographic paper which could be printed in contact with an unwashed negative and dried in a minimum of time, and here again the problem was successfully solved.

By combining these two techniques, suitably-designed machines would make it possible to produce a large number of copies of a document in a matter of seconds if this was required. A fully automatic machine of this type would of course be an expensive piece of equipment, and small organisations are more likely to be interested in the various improved forms of reflex copying systems. In making a reflex copy of a document a sheet of thin photographic paper is pressed into contact with the document to be copied and this is then exposed to light through the back of the sensitized paper. The difference in the amount of light reflected by the dark and light portions of the original document is utilised to form the photographic image. Upon development, a negative image is obtained from which any number of positive prints can be made.

Crude reflex copies can be made with ordinary photographic paper of high contrast. For best results special forms of so-called reflex bromide paper and specially-designed printing frames are recommended as a simple method of obtaining copies of documents at a cost of a few pence per square foot and minimum capital outlay.

Quality of Raw Materials

Turning from business to industrial efficiency, let us glance first of all at photographic tools which are helping to control the quality of raw materials. Most of these tools originated in research laboratories, because scientific research is based on efforts to reduce phenomena to forms that can be seen and measured. The powers of exact description provided by photography are the very foundation of precise knowledge and make it natural to use appropriate types of photographic

material as the retina of microscopes, telescopes, spectroscopes, oscilloscopes, stroboscopes, stereoscopes and X-ray tubes, converting them into recording instruments infinitely more versatile than the human eye.

Using these instruments enables us to reveal and record layer by layer the composition, structure and characteristics of materials. Starting at the outside, a beam of electrons, if suitably reflected from the surface on to a photographic plate, produces a diffraction pattern which reveals the arrangement of the atoms in the outermost layer of the reflecting body – of importance in the study of lubrication, polishing processes and other surface phenomena.

Photomicrography normally records the surface as the eye sees it. By sending a beam of electrons through thin layers of material an electron image of objects far smaller than can be seen by optical instruments can be recorded photographically. X-rays, when suitably reflected from surfaces, form diffraction patterns on photographic plates which will reveal the architecture of the molecular structure of matter to a depth of a few hundred atoms. X-ray micrography, in which X-rays transmitted by layers a few fractions of a millimetre thick are recorded on fine-grain photographic emulsions, yields radiographs which when studied under the microscope will settle such questions as whether the copper in a copper-aluminium alloy is in solid solution or not. Infra-red photography will penetrate thin crusts of rust and reveal, for example, the cause of porosity in tin-plating.

The now familiar radiographic and gamma ray techniques enable flaws and faults to be recorded even though they are embedded in the centre of steel a foot thick. Plates 11 and 12 illustrate how X-rays can show up the faults in a welded metal junction. Finally, the Betatron, which generates 20-million-volt X-rays, is extending this non-destructive probing for faults into even greater thicknesses of metal.

Some of these techniques are still in the laboratory stage. Others have already been harnessed as industrial tools as a result of the development of apparatus which can safely be

placed in the hands of people almost ignorant of physics. Of these techniques, let me illustrate three.

Spectrographic Analysis

The conventional method of determining the composition of materials is by chemical analysis, and this is still the most reliable method in the case of non-metals. The engineer's main raw materials are, however, metals, and in particular alloys, and here photography in conjunction with the spectroscope has freed hundreds of people from the boredom of routine analyses, for it yields, in a few minutes and at a fraction of the cost, results which would otherwise involve hours of laborious work. Spectrographic analysis as a technique was handed over to industry almost ready-made by astronomers who had perfected it in their efforts to determine the composition of the stars. Industrial spectrographic analysis is based on the fact that when elements are heated in, for example, an electric arc, they emit characteristic line spectra. In a mixture of substances the intensities of the lines of the various elements, as recorded on the photographic plate of the spectrograph, are related to each other in a way which depends on the percentage present.

Both qualitative and quantitative analysis of a minute particle of a substance is therefore possible in the few minutes necessary to expose and process a photographic plate and measure the densities obtained with a micro-densitometer.

Absolute methods of quantitative analysis in which the densities of the lines are interpreted directly as percentages are not yet reliable for a variety of reasons. On the other hand, the majority of routine works analysis is performed to keep a check on the uniformity of a product. Accordingly, specimens of accurately known and qualitatively similar composition are used as standards for the production of graphs from which the analysis is read off direct, the spectrum of these comparison standards being recorded for reference alongside that of the sample to be analysed. In

this way very high accuracy can be achieved by a purely routine procedure. It so happens that the 'sensitive lines' of metals (i.e., those which are in evidence when only minute quantities are present) lie between 2,000 and 10,000 Å., and are therefore accessible with a quartz spectrograph working in air and recordable only by photography. The sensitive lines of most non-metals are of wavelengths shorter than 1,850 Å., and here a vacuum spectrograph – a more expensive instrument – is required. Accordingly, although the economy in time and material with which spectrographic analysis can be carried out suggests that it may eventually replace the majority of routine chemical analytical control, as yet its chief industrial application has been metallurgy. The application of the method to the control of the composition of alloys has been one of the outstanding developments in the non-ferrous metal industry during the past ten years. Refining operations can be followed step by step, and many firms now control their foundry output by this method. In the case of alloys, the reference standards referred to above must have a known history, since the intensity of the lines in an alloy spectrum may vary according to whether the samples are in the as-cast state, the wrought state or in the heat-treated condition.

The working procedure has been reduced to a simple routine by the design of apparatus requiring a minimum of adjustments in use, and specially devised photographic plates whose characteristics facilitate the easy interpretation of the records.

Metallography

From the engineer's point of view the correct chemical composition of a structural material is, however, only half the battle. It may still be useless for his purpose if the constituents are not properly combined or the material is nonhomogenous. Unless, therefore, the engineer knows his material literally inside and out he must play for safety in designing castings, struts, and so on, compensating for

ignorance in this respect by undesirable dead weight. This is costly, and, in such machines as the modern aeroplane, impracticable.

Fortunately, in the case of metal alloys a thorough examination of the surface layers of properly chosen specimens will provide much valuable information about the metallurgical structure of the material.

The photographic examination of the surface of metals is called metallography. Such mechanical properties as hardness and ductility are related to the microstructure of metals and alloys, and numerous defects are directly attributable to abnormalities in this structure, which is built up of a mass of interlocking crystals. Accordingly, one of the main objectives of the metallographer is to obtain photo-micrographs of polished and etched metal surfaces, recording the nature and size of the individual crystals as in plate 29. Recording their change in size and nature with heat treatment, cold working and fatigue has helped to explain the basis of these phenomena and – more important – helped to bring them under the metallurgist's control.

Photography of the macrostructure, i.e., the structure as seen by the eye, not only helps in the selection of significant areas for photomicrography, but provides a record of markings indicative of unsoundness, cracking, segregation, and other faults.

The distribution of particles of sulphide in steel provides a clue to the process of crystallisation and can be recorded on the photographic emulsion without the use of a camera, simply by placing a sheet of bromide paper soaked in dilute sulphuric acid in contact with the polished surface of the specimen. Hydrogen sulphide is liberated locally by reaction between the sulphides and acid, and this in turn reacts with the silver halide in the photographic paper, forming a dark silver sulphide image.

X-ray Crystallography

X-ray crystallography is another typical example of the

development of a research into a works tool. This is a technique which reveals the molecular architecture of crystals by a study of the patterns produced when narrow wavebands of X-rays are diffracted during their passage through the material. The atoms of solid substances are always arranged in a characteristic manner which determine the physical properties of the material in bulk. The various patterns produced by diffraction by parallel layers of atoms are characteristic of these various geometrical groupings. The first interpretation of these spectra requires of course an expert physicist, but from the point of view of non-destructive testing the method can be used in a variety of ways by workers who need no more knowledge of the physics of the subject than the average owner of a wireless set has of the physics of radio. The interpretation of patterns produced by a modern industrial X-ray crystallographic unit is, in their hands, not so much in terms of crystalline structure as on such broad but informative lines as variations in heat treatment, corrosion, cold rolling, annealing and residual stresses. It is interesting to note that a 'picture' of a molecule showing the arrangement of the atoms in space can be made by working back from these diffraction data. A series of masks is made consisting of opaque bands whose widths and orientations are calculated from the diffraction records. Successive exposures on a single sheet of photographic paper are made through these masks and the superimposed record shows the spatial arrangement of the atoms in the molecule. This method eliminates the laborious calculations inherent in indirect methods of determining molecular structure from X-ray diffraction data, and the physicist's picture of a molecule which results is identical with that previously deduced from chemical evidence.

Fabrication Processes

Turning now to fabrication processes, perhaps the most potentially valuable development will be the wider application of a photographic technique which shortened by months

the period between the design stage and the first flight of the later types of aircraft. This is the so-called photo-template system. A template is a copy or pattern of some part of a mechanical structure. It is usually flat, made of metal or wood and carries construction details of the particular part which assist the fabrication and assembly of machinery or equipment.

Templates have been used since the beginning of the nineteenth century and some of the more elaborate modern forms require as many as 400 man-hours to draw out. Moreover, the laborious scribing operations involved have often to be carried out as many as half a dozen times. It has frequently been pointed out that a tremendous amount of time could be saved and risk of dimensional errors eliminated if these subsequent drawings were reproduced on the metal by photography. It was, however, the special combination of circumstances arising in mass production of war-planes that brought about practical development of this idea. A modern aircraft contains as many as 25,000 parts, whose outline at some stage had to be drawn on metal with an accuracy measured in thousandths of an inch. The design serves as a guide when the sheet is cut, filed, drilled or punched to make the aircraft part itself or the tools with which such parts are made. For the precision inspection and assembly of components, accurately made check template and assembly jigs are required, all produced from the same basic drawings. The high degree of precision essential, the complexity of the designs, the frequent modifications as design progressed, the need to ensure exact interchangeability of parts made in different aircraft plants and the vital need for speed resulted in the photographic reproduction technique becoming thoroughly established in American aircraft plants. Months of time and many thousands of pounds were saved on each design, and it seems certain that such methods will find peace-time applications in other engineering industries.

In a typical photo-template technique the design is scribed

once and for all on lacquered aluminium sheets. These are placed on suction copyboards and photographed down on to glass plates, using precision cameras of the process-engraving type. The negatives are then projected in the same apparatus on to sheets of aluminium sensitised with photographic emulsion (Plate 10).

The big advantage of this projection system is that the scale can be altered when required – for example, to allow for different degrees of shrinkage when the metal from which a part is to be made is changed, or when preparing small models for wind tunnel or other forms of examination. The projection process is, however, relatively costly to instal, for precision equipment is essential if the photographic image is to reproduce the original within the tolerances of typical specifications.

For small parts where no change in scale is involved a simpler and cheaper method is to make a reflex copy of the full-size drawing on a glass photographic plate and then print the negative down on to a metal sheet coated with a light-sensitive emulsion. Alternatively, the original drawing can be made on a translucent coating on plate glass and contact negatives made from this are then printed directly on to the sensitised metal. However produced, the metal prints are then cut out and become the templates or patterns that go to the shops.

It is claimed that photographic template methods have saved as much as £5,000 in building prototype aircraft and shortened the time between designing and test flight by from two to four months as a result of the reduction of time required to turn out patterns for shop fabrication. So far, only the aircraft industry has made any serious attempt to exploit the process. It would, however, seem immediately adaptable to motor-car and boat-building, even if only to facilitate the work involved in making mock-ups, i.e., full-scale models in wood, by photographically reproducing the original layout directly on the wood, which the builder would use immediately without the delay of marking out.

Photo-mechanical Processes

Photographic prints on metal are the basis of another major industry – photo-lithography – and here again war-time researches have made possible considerable simplifications in the working procedures. Thus the rapid production of maps in the field was facilitated by the preparation of zinc plates coated with photographic emulsion on to which negatives could be projection-printed. A simple processing technique resulted in litho printing plates ready for use. Although this technique simplified printing plate production it did not cheapen it, and further development of this technique may well be of greater interest to business houses who already employ simplified photo-litho methods for preparing their own literature rather than to litho printers as such.

The introduction of so-called 'coloured contact screens' which eliminate the necessity for skilled hand work in reproducing half-tone illustrations is however an important advance. These screens may well represent the most important improvement in the half-tone process since the introduction of the ruled screen itself. They enable the contrast of the final printing plate to be adjusted to that of the original as a result of making controlled variations in the colour of the printing light, and at the same time they automatically yield a much closer approach to accurate tone production than can be achieved by the conventional half-tone process.

A typical photomechanical printing plate is in effect a photograph in metal, and by making the original drawing a suitable design it became possible to make exceedingly delicate metal devices – such as the grids of valves or the hair-line resistances known as strain gauges – by stripping the metal photograph off its temporary glass support.

Sometimes, as in the thousands of hair-line graticules which were used in gun sights, the metal image is left on its glass support. By using substantially grainless photographic emulsions the lines on such graticules were quite free from graininess and could, when necessary, be made so thin that

as many as 1,200 separate lines could be produced in each millimetre width.

Quality of the Product

Radiography. – The war also led to a considerable increase in the use of photographic methods for examining fabricated articles. The most important of these was radiography – the recording of X-ray images on photographic film or paper.

X-ray pictures are essentially shadowgraphs made by placing the object to be examined between the X-ray tube and a fluorescent screen or a light-tight cassette containing photographic film. The image which is seen on the screen or recorded on the film is produced by differential absorption of the radiation during its passage through the specimen and when articles made of light metal and of low economic value are to be examined as manufacturing routine, visual inspection of the image is the usual practice. Examination of the core of golf balls, flash lamp cells, or of the electrode assembly of small radio valves are typical examples. The method is also useful for the inspection of lower-grade light alloy castings. The photographic method is, however, essential for dense materials, for the examination of fine detail and where records are required to meet a specification. Typical examples are the checking of the proper alignment of the inner components of sparking plugs, shell fuses, torpedoes, electrical condenser units and vacuum pumps. In some cases visual and photographic inspection is profitably combined. Thus the centering of the core of a heavily-insulated cable can be viewed at right angles as the cable is drawn behind the fluorescent screen. On seeing a suspected region, the operator throws a switch, thus making a radiograph and marking the region in question on the casing.

During the development stage of an assembly, X-rays will help to demonstrate why a device fails to function, examples being the revealing of the presence of drops of solder which may cause short circuits, or, in the case of a Bourdon gauge, interfere with the hidden moving member.

The value of X-rays as an inspection tool has been clear since Röntgen made the first half-dozen radiographs some 45 years ago, for five of these were typical of the subjects now examined by the industrial radiographer. The early industrial applications of X-rays were, however, attempted with adaptations of apparatus primarily designed for medical work, and it was only when equipment specially designed for industrial use appeared that radiography came to be regarded as an essential engineering technique.

Typical industrial equipment is mobile and can be applied to structures in situ. It thus becomes possible to determine the position of concealed wiring and plumbing, determine the general character of the reinforcement in old concrete floors to be used for supporting new machinery or check telephone poles in the highways for unsound wood. Repeat radiographs of old timber will show whether death-watch larvæ are alive by recording any change in their position. These are more or less specialised applications, however, and it is in the foundry and welding shop that X-ray equipment has become imperative.

It is now quite common for specifications to demand radiographs of welds and castings, for X-rays will demonstrate the presence of cracks, blow-holes and slag or sand inclusions which might otherwise be revealed only after expensive machining, or remain as an undetected menace to the soundness of structures on which our lives may depend. Not only does radiography reduce machining costs by keeping unsound parts from the production line but, by showing the nature and location of irregularities, it indicates methods of avoiding them, thus increasing the yield from such raw materials as castings. Because radiography enables soundness to be assessed it often permits the use of lower cost materials and fabrication methods, as when sand castings are substituted for forgings or spot welding for slower rivetting. Accordingly, no high-pressure welded boiler receives a Lloyds' Class I certificate unless radiographs of every weld are forthcoming, and every light

alloy casting used in aircraft construction is first submitted to X-ray examination. The thickness of metal which can be penetrated is directly related to the kilovoltage of the X-ray set, and a modern portable industrial unit employing 400 kilovolts will penetrate up to 5 inches of steel. For thicker or inaccessible specimens gamma rays are employed.

Gamma Radiography

Whereas the wavelengths of X-rays are approximately one hundred thousand times smaller than those of visible light, gamma rays are nearly one million times shorter, and we have to employ one million volts to generate them by the technique used to produce X-rays.

Radium is a natural source of gamma radiation, and a radium bomb – that is, a tiny fragment of a radium salt enclosed in a platinum capsule in a protective lead cylinder – is all the equipment required. Exposures of the order of several hours are given by removing a lead plug in the cylinder, and radiographs through 8 inches of steel are possible. Radon, which permits an even smaller source of high gamma-ray intensity, is to some extent replacing radium in industrial radiography. It is highly probable that artificial radioactive elements will also be employed for this purpose in the future.

X-ray equipment has been devised which will yield gamma rays. An example is the Betatron, which is essentially a specialised form of transformer in which the secondary consists of electrons rotating in a ring-shaped vacuum tube. At a certain point in the alternating current cycle an additional high voltage pulse is applied to the primary, causing the electron orbit to expand. The electrons in consequence strike a platinum target, producing million-volt X-rays which will penetrate 20 inches of steel – a thickness far beyond that economically practical by other means.

High-speed Radiography

For the majority of industrial work, an exposure of seconds

is of little consequence, but a new type X-ray tube permits radiographs to be made with exposures of 1/500,000th second. The tube is so designed that currents of the order of 2,000 amp. can be passed through it as a result of condenser discharge, and radiography of rapidly-moving enclosed machine parts, such as pistons or the impeller blades of turbines, has become practical.

The silhouette photograph of a golf ball at the moment of impact aroused admiration a few years ago, and we had hardly recovered from the surprise created by Edgerton's substitution of a fully-detailed photograph for this silhouette when with this new technique we obtained a record of how the inner core of a ball behaved at the critical instant (Plates 26 and 27).

Let us now turn to techniques of value in assessing the performance of machines and in search into new designs.

High-speed Photography

One of the earliest triumphs of applied photography was the freezing of the image of events lasting minute fractions of a second, thus permitting their study at leisure. The subject was illuminated by an intense flash of light produced by the discharge of an electrical condenser across a spark gap. Various types of circuit have been devised, some of which yield a flash shorter than one millionth of a second.

In a convenient modern light source the discharge takes place across a gas-filled tube yielding a flash of intensity equal to 50,000 40-watt bulbs with an effective photographic duration of about 1/30,000 second. The tube has a life of well over 5,000 flashes. Typical of the engineering applications of such equipment is the photography of an aeroplane propeller revolving at high speed and determination of the amount of distortion during rotation by making measurements on the photograph. Plates 13 to 16 show how this kind of work can reveal the very rapid feeding movements made by some animals.

Flashlight technique of this type permits the use of an

ordinary camera. When, however, the subject is luminous, specialised forms of camera are necessary. Thus, in studying the propagation rate of burning explosives, photographic film has been attached to drums driven at right angles to the direction of flame travel and so caused the flame to draw graphs which enable the changing speed of the explosion wave to be measured. Spinning mirrors have been used to move the image of such flames over a stationary photographic plate and so record the life history of explosions lasting minute fractions of a second.

I suppose the most photographed event in history was the atomic bomb explosion at Bikini. Five hundred cameras of many different types were employed and more than 100,000 still pictures and three million feet of cine-film were exposed during the two tests. Much of the data on the potential destructive force of these bombs will be based on these records.

High-speed Cinematography

It is obvious that a cine-film record is a valuable way of analysing a movement. For many purposes an ordinary cine-camera used at normal speed is quite adequate. Very often, however, it is not convenient to photograph the actual movement itself. When the movements are too small they can be magnified by the use of a follower connected to a suitable dial gauge which is photographed. When they are too complicated, numerous or inconvenient to record directly, as in the analysis of the performance of an aircraft in flight, dials and cathode ray tube screens which record such data as air speed, altitude, bank and stresses and strains in various parts of the machine can all be collected on one panel which is recorded by a normal speed cine-camera (Plate 32).

New fields are opened up when the camera is speeded up. Phenomena whose life history is too short-lived to be examined by the unaided eye acquire a new significance when the time scale is altered by slow motion (high speed) cine-

matography. Details of displacement and distortion of objects in rapid motion are directly observable as a function of time when the film is projected at normal speeds, while velocities and accelerations can be calculated from frame-by-frame measurements.

Typical engineering applications are the observations of oscillations or surges in valve springs, the hunting of synchronous motors, the functioning of telephone relays, clutches, ringers and dials; coin-collecting mechanisms; contact conditions and the arcing of switches at make-break. It has proved of value in studying such diverse problems as the behaviour of high-speed loom shuttles and observations of warp breakages, the melting of fuse wire during a burn-out and the detection of gas leakage around the charge in a gun when fired. It has been applied to the testing of materials in connection with impact testing, stress analysis and bending moment, and to the reduction of noise in such apparatus as typewriters and accounting machines. Valuable studies from the design point of view have also been made on such relatively slow-moving machines as milling machines and punch and hydraulic presses. Thus it will reveal erratic operations caused by excessive deflections and clearances, and information relating to punch and die adjustment and to the flow of metal during punching operations.

If the movement to be studied is rotary or rhythmical, it is well known that it can be apparently slowed down by viewing the subject by stroboscopic light of appropriate frequency. A typical example is the study of the flow of air through a fan blade, smoke being fed into the air stream to make the air currents visible. In such cases the record can, of course, be made in an ordinary camera, but the method is of limited application. Genuine ultra-speed cinematography demands radical redesigning of the camera itself, because the film must rush through the camera at about a mile a minute, a speed which effectively rules out the possibility of its normal method of progression – alternate stops and starts.

A laboratory type makes use of an argon-filled discharge tube capable of flashing from 1,000 to 5,000 times per second. No shutter is used on the camera since each flash lasts only 1/250,000th second, and the film does not move appreciably during this period.

In commercial ultra-speed cameras, moving optical devices are built into the camera which send the images formed by the lens streaming along in synchronism with the rush of the film. Thus, for a very brief time, as the film and image flow together, each image is stationary with respect to the film. Perhaps the simplest camera of this type is the Eastman High Speed camera which uses a rotating glass block. Although this camera can record up to 3,000 pictures per second, 1,000 pictures per second is adequate for the study of most machine parts. Naturally, instruments of this type are fairly costly, and since the majority of engineering firms could only find occasional use for them, it is usual for them to hire the equipment, together with a trained operator as and when required.

Cine-records of the movements made by workers engaged on repetition jobs can be analysed in a similar manner in order to determine the most efficient and least tiring sequence of operations. As an example, a step-by-step analysis of a timed cine-record of a girl sorting spools led to the devising of a method which increased her output 80%. The sorters find the new method less tiring and, being paid on an output basis, everyone profits by the change.

It has been suggested that making such records on infra-red sensitive film would have the psychological advantage that the worker would not be disturbed by the obvious presence of a flood of additional lighting which is necessary when ordinary cine-film is exposed in typical workshops. The recent spectacular increase in the working speed of infra-red emulsions makes such a proposal quite feasible.

For the so-called 'micro-motion study' of repetition movements a cine-record is not necessary. Instead, small lamps can be attached to the moving parts of the operator's body,

their light being then recorded over one cycle of the operation by working in a dimly lit room while the camera shutter is left open. If the lamps are made to flash at a uniform rate, the speed of the operator's movements can be calculated as well as their path. When two hands are employed – as in the case illustrated in Plate 42, saw-tooth modulations of different types can be employed in each lamp to facilitate sorting out on the photograph of the movements made by each. The figure shows a girl collating the sheets of a manuscript. The movements made by her hands along the desk are revealed by the intermittent light trace. The greater smoothness of movements, speed and economy of effort resulting from a rearrangement of the positions of the various piles of paper is seen in Plate 43. Messrs. W. H. Smith used this technique to study the movements made by a typist in making out invoices. This led to a rearrangement of the data on the form, which reduced the time of typing each form by two-thirds.

Here again, by working in a room lit with fluorescent light – which contains no infra-red radiation – the lamps attached to the worker's wrists can be covered by visually opaque infra-red transmitting filters and the record made on an infra-red emulsion. This adaptation of a war-developed technique used in training the pilots of night fighters has the advantage that the operator can work under normal illumination conditions and with a minimum of distraction due to the presence on her wrists of the recording lamps.

Photoelastic Analysis

Many faults in the operation of machines are due to stresses whose existence it is impractical to predict at the design stage. Valuable guidance can, however, often be obtained by the technique of photoelastic analysis.

A scale model is made of the object to be tested, using a suitable transparent material. Loads proportional to those acting on the real object are applied to the model, which is then examined by polarised light. An unstrained model

placed between crossed Polaroid screens appears uniformly black under these conditions. Whenever stresses occur, however, the refractive index of the material is altered and bright lines will appear which contour the principal stresses, providing valuable information as to the internal conditions of a similar shaped metal object under similar conditions of load (Plate 30).

If the model is made of a thermo-setting plastic the stress pattern can be rendered permanent by heating the model while it is under load. It can then be cut apart for three-dimensional stress analysis. Calculation of the stresses in all such cases involves measurement of the distribution of the pattern, and this is materially simplified by making these measurements from photographic records – particularly when the stresses are dynamic in moving parts. Here, a cine-film record is the only practical way of assembling the data in measurable form.

Conclusion

This review has been an attempt to demonstrate how certain photographic techniques originating in research laboratories have so far contributed to industrial efficiency.

New ways of harnessing photography as a research tool are constantly being devised, for its powers of exact description are the very foundation of exact knowledge.

It was Eddington who suggested that all that could ever be known of Nature consisted in essence of pointer readings. Certainly the scientific research worker nearly always takes pains to arrange his experiments so that the final observation employs the sense of sight, and the ways in which photography can be used to produce records for visual inspection is limited only by the ingenuity of the worker. Its value for recording invisible radiations is obvious, but even when the eye might appear to be an easier or quicker means of making a record, the camera is often a convenient tool for eliminating drudgery and ensuring accuracy, as when it watches dials, counts dust particles, records pressures, and so on.

Tiny pulsations due to subtle faults in machines can be recorded and enlarged until not only is their presence demonstrated, but measurements which reveal their cause become possible. The differences of refractive index in the laminæ of hot and cold air produced by stringing heated wires across a wind tunnel can be recorded and intensified so that even air currents may be photographed.

In many cases, such as the movement of the light spot on the cathode ray oscillograph, the human eye can only see the movement as a blur of light and the moving photographic film is an essential tool for reducing the record to intelligible form. In others, as in the transient tracks produced in cloud chambers by subatomic particles, photography is the only way in which a record can be made for subsequent interpretation and measurement. When the disintegrating atom is embedded in a photographic emulsion the tracks made by its debris of charged particles are produced by direct action on the silver salts. Measurement of these tracks made permanent by development enables the energy and momentum of the various particles to be determined, thus providing the vital key to the interpretation of the atomic explosion (see plate 31 in *Science News* 5). It can therefore safely be claimed that but for photography our hopes of harnessing atomic energy would remain a novelist's pipe-dream.

I think it will be obvious that many of the techniques described are highly specialised and can only operate at maximum efficiency when the behaviour of photographic materials under a wide variety of conditions is properly understood and catered for. It is therefore a matter of regret that as yet not one of our leading universities has established either a teaching course or a research department on Photography. In Germany, before the war, nine universities offered training and facilities of the type required, in Japan two and in Italy four, to refer to our late enemies alone. In England such courses as are available are intended primarily for professional photographers; and those enterprising

industrialists who wish to make use of this twentieth-century tool for solving one of their twentieth-century problems must as yet rely on their own resources, or the technical service departments of the photographic manufacturers, for essential guidance on photography as a record-maker in the widest sense.

However, a committee appointed by the Royal Photographic Society has recommended the establishment of a readership in Photography within a British university. Such a course would be a valuable first step in ensuring a supply of thoroughly competent workers of the type required if we are to take full advantage of this potential contribution to our industrial efficiency.

This article is based on two of the Cantor Lectures on Photography which the Author gave to the Royal Society of Arts in March, 1947.

Mathematical Instruments and Calculating Machines

DR GABRIELE RABEL

WHO are ENIAC, EDVAC and EDSAC?

If you think they are old Anglo-Saxon kings from the days of 1066 and all that, your guess is wrong. ENIAC is an Electronic Numerical Integrator and Calculator, and EDVAC and EDSAC are persons of a similar character.* ENIAC and EDVAC are of American parentage, EDSAC is English, a native of Cambridge. Their remote ancestor is Calculus who, surprisingly, was a simple pebble. Thracians, we are told, set aside dark calculi to count their dark days and white calculi to add up the happy ones. Another ancestor is Abacus, a board on whose drawn lines (or rods or wires) counters are pushed along. One form embraces Heaven and Earth, earthly beads counting as one unit, heavenly beads as five.

No improvement of mathematical machinery is reported before Napier's Bones (1617) which were a kind of movable multiplication table. The seventeenth century is characterised by vigorous endeavours to 'rationalise' mathematical practice, relieving the worker from mechanical repetitive procedure to free his mind for real thinking. One approach to this goal was to simplify the *language* of mathematics through various systems of notation and the symbolical calculus as devised by Vieta, Descartes, Newton and Leibniz. Another path to the same goal was the relegation of all mechanical work to machinery. In 1642, Pascal built the

* DV stands for Discrete Variable, and DS for Delayed Storage. E always means Electronic, A Automatic, and C Calculator. The ENIAC has been in use for some time, the other machines are still *in statu nascendi*.

Arithmometer and, inspired by this addition machine, Leibniz made a better one. He is also said to have constructed an algebraical machine for the solving of equations.

In the early 19th century, a young mathematics professor in Cambridge, Charles Babbage, dedicated his life to the idea of saving the time and brains of mathematicians by means of mechanical aids. He devised two types of machines, which he called Difference Engine and Analytical Engine.

The Difference Engine is based on an arithmetical law which appears to the layman almost miraculous. If we form the squares of the numbers 1, 2, 3, 4 etc., we get the series 1, 4, 9, 16, 25, 36, 49 ... and find that the differences between them are 3, 5, 7, 9, 11, 13 .. so that the differences of the second order are constant=2. The first differences of the cubes 1, 8, 27, 64, 125 ... are: 7, 19, 37, 61 ... the second differences: 12, 18, 24 ... so that the differences of the third order are again constant=6. Somewhere the differences of any such sequence seem to become constant, and this gave Babbage the idea that one can build up tables by adding differences. His Difference Engine was to compute any kind of tables (e.g. of logarithms and trigonometrical functions) both more quickly and more correctly than was possible before. But the machine remained unfinished for lack of funds, and for the same reason the Analytical Engine could not even be begun – which is a great pity, for it was designed in full detail and meant to be a 'General Purpose Machine' like the ENIAC.

The mechanical aids to mathematics are of two distinctly different types which Professor Hartree distinguishes as 'Mathematical Instruments' and 'Calculating Machines,' while the American engineers call them 'Analogue' and 'Digital' machines. It is essential to understand what constitutes the difference between them.

Two mathematical instruments, the Slide Rule and the Planimeter, are widely known. The purpose of the planimeter is to find the area of a figure encompassed by a given curve. If a pointer connected to a wheel is made to follow

this curve, its sideways movements combined with the revolutions of the wheel make it possible to read off the area under the curve. Mathematically one finds the area of a rectangle by multiplying width and height. If a figure has an irregular contour, one can divide it into a great number of narrow rectangles and sum up these small strips. If the strips are supposed to be infinitesimally narrow and their number infinitesimally great, the summation is called integration and the rough-hewn sign for a sum Σ mellows into the more elegant yet widely dreaded sign $\int$ which denotes an integral. The planimeter achieves mechanically what integration achieves mathematically. The figures submitted to the planimeter are often symbols for physical quantities, e.g. the indicator diagram which measures the efficiency of a steam engine. Otherwise the curve may represent any mathematical function whatever. Some of the most complicated instruments called Integraph, Integrator or Differential Analyser may be roughly described as one planimeter working on top of another. One integraph uses optical methods. It measures very small and irregular areas by the amount of light they transmit. Another much-used type of 'Analogue' is the Electrical Model, especially handy for the solution of flow problems. To find the distribution of the current in an extended network by computation implies the solution of a great number of linear equations; it is easier to build a model of the network adjusted to the given conditions and to carry out simple measurements. Such an electrical model can be used for networks of any kind, because the laws of flow are similar for electric charges, gases, water, steam or heat, and it is simpler to insert an ammeter into an electric circuit than, say, a flow meter into a pipeline.

These few examples suffice to illustrate the principle of a mathematical instrument or Analogue. Numerical data are not used directly for computation, but translated into physical quantities. In the slide rule, numbers are represented by lengths, in the planimeter by lengths and areas, in the

electrical models by amperes, ohms and volts. We might perform a simple multiplication such as 13×0.74 by using the formula Voltage$\doteq$Current$\times$Resistance. If we send through a resistance of 13 Ohms a current of 0.74 Ampere, we may read from the voltmeter the product 9.62 Volts.

But obviously the result is burdened with all the inaccuracies of measuring instruments and there is a limit of accuracy even for the finest instrument.

The situation is completely different in digital machines. They deal with numbers as such and usually count some discrete events, e.g. electrical signals. They cannot, like the Analogues, handle continuously varying quantities; if asked to solve differential equations, they must confine themselves to summation and cannot pass on to integration. But their accuracy, not depending on physical measurements, is the same for the 10th or 20th decimal as for the first.

It is not the purpose of this article to describe any one machine fully. I have only tried to clear up, first for myself, then for others, the elementary principles of such contrivances. This, I found, can best be done by reverting to the first modern calculating machine as sketched by Babbage a century ago. At that time the Jacquard Loom had just been invented and its punched card method was eagerly seized upon by Babbage. He writes: 'The Jacquard loom weaves any design which the imagination of man can conceive. The patterns designed by artists are punched by a special machine in sets of pasteboard cards and when these cards are placed within the loom, it will weave the desired pattern – either as a damask cloth if warp and weft are of the same colour, or using different colours.' 'The analogy of the Analytical Engine with this well-known process is nearly perfect. The Engine consists of two parts: (1) the Store in which the variable to be operated upon and the results of operations are placed; (2) the Mill into which the quantities are brought to be operated upon. Every formula which the Engine can be required to compute consists of algebraical operations to be performed upon given letters and of modi-

fications depending on the numerical values assigned to these letters. There are therefore two sets of cards, the first to direct the nature of the operations, the other to direct the particular variables on which those cards are required to operate ... The Engine is of the most general nature. Whatever formula it is requested to develop, the law of its development must be communicated by two sets of cards.' Some professor inquired what the machine could do, if in the midst of algebraical operations it was required to use logarithms or trigonometrical functions. Babbage answered that the machine might compute the desired numerical values in the shortest possible time, but that it might also use punched card tables. 'Suppose the engine required the logarithm of a given number, it will stop, ring a bell and ask for it. Thanks to the configuration of holes, only the right logarithm will fit the given number. If the attendant has brought the wrong card, the Engine will ring a louder bell.' Babbage adds: 'It will be an interesting question which time only can solve whether tables on cards will ever be required, for the computations made by the Engine are so rapid that it may make shorter work by computing direct from formulae.'

The problem is not solved yet. The ENIAC uses ready-made tables, another American machine does not. And concerning a 'punched card memory' Professor Hartree reasons that 'though it greatly increases the power and range of the machine, it does so at the expense of the speed and fully automatic character of the work.' It is still true that cards require human attendance, and humans are so slow!

One of Babbage's greatest worries was the carrying over of the tens. In principle the problem was solved by Leibniz' toothed 'stepping-up wheel' which, when passing from 9 to 0, moved another wheel by one tenth. But what troubled Babbage was the time required for the carriage. 'I concluded that nothing but teaching the Engine to foresee and then act upon that foresight could achieve an unlimited number

of carriages in one unit of time.* He actually succeeded in devising a mechanism by which all the movements the carriages required when adding two ten-digit numbers were made at once instead of successively, and he estimated that, if the velocity of the moving parts were forty feet per minute, one addition or subtraction could be completed in one second.

The ENIAC completes 5,000 additions in one second. The punching system for giving instructions and for registering results is still in use, a card reader scans the punched cards and electrical contacts are made through the holes. Thus the card data are conveyed to the 'Constant Transmitter' which makes them, in the form of electrical signals, available to other units. Babbage's two sets of cards are supplanted by two sets of communication lines – programme lines transmitting pulse groups which represent instructions, and digit lines transmitting pulse groups which represent numbers. Further all the thirty ENIAC units are permanently connected to a third set of lines which supplies a standard pattern of pulses from the Cycling Unit. This contains an oscillator which runs at 100,000 cycles per second. By a Pulse is meant a change of voltage, positive or negative with respect to some reference level. Each pulse lasts two microseconds (0.000002 seconds). The standard pulse pattern is repeated every 200 microseconds. This period is the unit of time for the ENIAC, for it is the time it takes for an addition. Other operations require multiples of this period, e.g. a long multiplication takes 13 addition times.

The pulses are the money which causes the machine to be a going concern. The Cycling Unit is the mint which issues the coins, the constant transmitter a bank or clearing house. The pulses distributed to the various units stimulate the operations all round and synchronise them. When one unit has finished its work, it may transmit a pulse to another unit as an order to perform in its turn.

Each of the thirty units has more than one function. Their electrical interconnection depends on the plan of

operations and is done by hand, but when once set, the machine performs extended sequences of computations automatically. Special instructions are given to each unit, but a 'Master Programmer' controls the work as a whole.

The basic unit is the *Accumulator*. An accumulator is a storing device. The chemical accumulator stores energy, the ENIAC accumulator numbers. But it also adds numbers. This it does through electrical counters. Each accumulator contains 10 decade counters and each decade counter 10 gadgets with the rather flippant-sounding name 'flip-flop'.

A flip-flop is a pair of vacuum tubes, each of which possesses three electrodes (a triode), namely (1) the Cathode which when heated, emits electrons, (2) the Anode which receives the electrons, and (3) between anode and cathode the Grid. If the voltage applied to the grid rises above a certain amount, current flows from the anode to the cathode.

Vacuum tubes of this kind often act as amplifiers, but

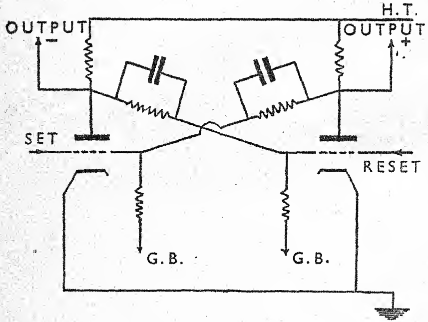


Figure 17—A flip-flop electronic counter circuit.

here they perform another service. The emission of a signal depends on whether a tube does or does not conduct, while the magnitude of the current is irrelevant. When a tube is non-conducting, there is a considerable difference of potential between anode and cathode, but when current flows through, the anode potential drops and at this moment it emits a negative signal to the outside. When its voltage rises, it emits a positive signal.

The two triodes of each flip-flop are so interconnected that never do both tubes conduct at once. A flip-flop is said to be 'on' or 'set' when its left-hand valve conducts and then only an indicating neon lamp glows. When the right-hand tube is conducting, the flip-flop is said to be 'off' or 're-set'.

The ten flip-flops within a decade counter represent from left to right the digits 0 to 9, while the whole decade represents one place of a ten-digit number. Suppose the number 6,093,528,012 were held by the accumulator, 6 would appear in the first decade counter, 0 in the second etc. The counters count electrical pulses which come, directly or indirectly, from the Cycling Unit. The 10 flip-flops within a counter ring are so connected that at any time one of them only can be 'on', and that reception of a new pulse (which alters the grid potential) causes the one flip-flop which is 'on' to be re-set and its successor to be set. This is the actual counting process. It means that the counter advances, say, from stage 4 to stage 5 and, after the next pulse received, to stage 6. Not all adding machines operate thus by actual counting. Some use addition tables.

When a counter has reached stage 9, and receives a further pulse, the last stage is re-set and the first is set, while at the same time a carry-over pulse passes to the next decade.

Subtraction is treated as a form of addition, grocer fashion. When you give your grocer a pound and your bill is 11/6, he will not say 20 minus 11/6 is 8/6, he will add on to 11/6 until he reaches 20. Here is an example of how it is done. P means plus, M minus. If 801 is to be subtracted from 527, the complement 10^{10} minus 801 is added. Thus:

P 0 000 000 527
M 9 999 999 199

M 9 999 999 726

The last line is equivalent to (–274). There is a special mechanism through which an accumulator can deliver the complement of the number which it holds.

Multiplication can be done by repeated addition, and division by repeated subtraction. But the ENIAC uses a multiplication table and has a special square-rooter and divider. Division always takes much time, but in practice it can mostly be avoided.

Each accumulator has channels for receiving and transmitting digit pulses and others for programme pulses. What it does when a programme pulse reaches it, whether it receives or transmits, whether it does so once or repeatedly, whether after transmitting a number to another unit it continues to hold it or clears it away, depends on the position of switches on the programme channel.

There are no special devices for solving algebraical and differential equations. The formulae are broken down into sequences of simple arithmetical operations, integration into step-by-step summation; the machine evaluates squares or cubes or roots and adds or subtracts the results. A group of operations may have to be repeated many times, or again the regular repetition may have to be interrupted. Sometimes the moment for a change in operations cannot be specified beforehand and the results themselves determine automatically which course the machine should follow. Indications for a new course may be a negative sign, or equality of two numbers, or a certain difference between them.

That the various units must be connected by hand, using legions of plugs and switches, is one of the drawbacks of the ENIAC. Another imperfection is its insufficient storage capacity. There are only 20 accumulators and each of them can only hold one ten-digit number. Further the ENIAC's

requirements in space and electric equipment are enormous – 18,000 valves, 5,000 switches, 150 kilowatt power.

The new machines now under construction will work with one tenth of the valves and of the power and will connect the various units automatically. The EDVAC is developed in America, the A C E (mentioned in *Science News* 5) in the National Physical Laboratory in Teddington, and the EDSAC in Cambridge by the director of the Mathematical Laboratory, Dr M. V. Wilkes, who specialises in combining mathematics with electronics. The common feature of these machines is a new and surprising method of storage. A six-foot tube filled with mercury terminates at both ends in a piezo-electric quartz crystal. Such a crystal transforms pressure changes into electric impulses and vice versa (see Page 49). Thus, if signals in the form of electric waves reach the entrance quartz, it transforms them into high frequency sound waves. These travel through the mercury column and the second crystal reconverts them into electric impulses. In this form they make their way back to the first quartz and keep circling round like a moving staircase. The different rhythms or patterns of the signals represent partly instructions, partly numbers. As they leave the mercury tube, they can be selected and switched into the operating circuits so as to enter into the required operations.

Each 'memory-unit' consists of 16 tubes containing 200 lb. of mercury. Dr Wilkes plans to employ two such units with a total storage capacity of 500 ten-digit numbers. He hopes to have the machine ready for a rough testing by the end of 1948. Refinements are to be introduced later.

The new machines will use a new counting system. The fact that valves have only two positions, 'on' and 'off', has suggested the application of the binary system of notation instead of the customary decimal notation.

In the latter the symbol 1111 means $1\times10^3 + 1\times10^2 + 1\times10^1 + 1\times10^0 = 1111$. In the former the symbol 1111 means $1\times2^3 + 1\times2^2 + 1\times2^1 + 1\times2^0 = 15$; and the symbol 1010 signifies $1\times2^3 + 0\times2^2 + 1\times2^1 + 0\times2^0 = 10$.

There are no other figures but 0 and 1. A closed valve transmits no signal, an open valve one. A second signal reaching a valve necessitates carrying over as the tenth does in a decade counter. All this looks very awkward, but the system requires less complicated equipment.

A machine which can make 1 million multiplications in an hour, opens new possibilities. A scientist need no longer shrink from tackling a problem which requires several million multiplications, he need only give instructions to the machine, which will accomplish the work in a day. Quite a number of scientific domains are mentioned which baffle the physicist, not by the difficulty or profundity of the mathematical operations implied, but by the sheer amount of numerical work to be carried out and the multitude of equations to be solved.* This type of perplexity has faced scientists dealing with the structure of atoms and molecules, the movements of water and air, the results of X-ray crystallography. But the whole realm of statistics and economics, too, is waiting for the machine.

The 'Electronic Brain'

It is always much easier to introduce a false term than to evict it. The term 'electronic brain' has probably come to stay, but it must be handled with care.

Professor Hartree explains: 'The automatic control of the computing sequence by the results of the calculation itself endows the machine with "judgment" in a restricted sense, and I think it is this, or possible developments of it, which has led recently to the use of the term "electronic brain".' But it must be clearly understood that the situations requiring this judgment, the criteria to be applied, the assessment of the results of applying them and the decision on the action to be taken on the basis of this assessment, all have to be foreseen and appropriate instructions to be worked out in setting up the machine. It can only do strictly and precisely what it is told to do.

* for instance, see *Science News* 6, page 72.

'It is disconcerting how literally it takes even the most "phoney" instructions' ... It will go on for ever, say, trying to divide by zero, which no human computer would do.

Dr Wilkes observes that the ENIAC is the equivalent of a desk calculating machine plus operator, the operator being a moron who cannot think but can be trusted to do exactly as he is told.

In a letter to the *Times* (7.11.46) Professor Hartree admitted that the ENIAC exercises 'a certain amount of judgment' whereupon Sir Leon Simon asked what exactly was meant by this phrase, and suggested that Hartree's left hand had given back what his right hand had taken away. Hartree, after repeating the above quoted description, added: 'It is this faculty of selection of one procedure from several alternatives on the basis of specified criteria that is meant in writing of a machine as exercising a certain amount of judgment – a certain amount. The machine can only deal with those situations covered by the instructions supplied to it, and every step has to be foreseen and thought out by the operator and supplied to the machine as operating instructions.'

It is interesting that Babbage too ascribed judgment to his Engine. I make four objections against the phrase 'a certain amount of judgment': (1) Judgment is a faculty which one either has or has not. It is the knowledge and training that form the basis of correct judgments of which one can have a certain amount. A farmer may show excellent judgment as to crops but none as to Kant's philosophy, while a profound judge of philosophy may be unable to judge crops. Has each of them a certain amount of judgment? (2) Judgment must be conscious. If a horse finds its way to the stable while asleep, it does not exercise judgment. (3) It must be possible for a judgment to be false. The ENIAC's judgment is necessarily correct. But if it did make a mistake, whom would the engineer scold, the machine or himself? Judgment and responsibility are inseparable, even in courts of law. (4) To judge and to assess a criterion are

mental faculties, and to ascribe mental faculties to a machine may appear as one step towards declaring that "man is only a machine" – quite against Professor Hartree's own intentions. Others have found it possible to describe the activities of the ENIAC without using these terms.

Sir Charles Darwin, again in that instructive *Times* correspondence, wrote: 'In popular language the word "brain" is associated with the higher realms of the intellect, but in fact a very great part of the brain is an unconscious automatic machine producing precise and sometimes very complicated reactions to stimuli. This is the only part of the brain we may aspire to imitate.'

Let us imagine some future machinery imitating in all details the activities of our brain. You may call it boldly an electronic brain, as long as you do not imagine that a brain thinks. The term 'electronic brain' is only dangerous if applied in the spirit of Karl Vogt's much-quoted dictum that the brain secretes thought as the kidney secretes urine, and if it aims at confirming that shallow creed that man is only a machine. There is no harm in using it if we realise that it is not the brain but the mind which thinks, that our mind is not the product of the brain, that generations of minds have built up the brain as generations of engineers have built the calculating machine and that the mind uses the brain as an engineer uses his calculating machine.

D. R. Hartree, *Nature*, 20th April, 1946 and 12th October, 1946; *Calculating Machines*, Inaugural Lecture, Cambridge University Press, 1947; *Journal of Scientific Instruments*, vol. 24, July, 1947; *Royal Naval Scientific Service Journal*, July, 1947; M. V. Wilkes, The ENIAC, *Electronic Engineering*, 19th April, 1947; Goldstone, *Mathematical Tables and Aids to Computation*, vol. 2, p. 97, 1946. Complete description of the ENIAC.

GLOSSARY

ANISOTROPIC crystals are crystals which have different physical properties according to the way you look at them. Thus such a crystal may show a greater resistance to the passage of an electric current when its east and west faces are connected in the circuit, than when it is turned ninety degrees and connected through its north and south. Anisotropy is a reflection of dissymmetry in the internal molecular make-up of the crystal.

BALLISTICIAN: One who studies the mathematical laws governing the aiming and firing of projectiles.

BITUMEN: crude tar.

CHEMOTHERAPY: The study of chemical substances which may be valuable in the treatment of disease.

CORONARY THROMBOSIS: The heart, like other organs, has a special supply of blood to nourish its muscle, in addition to the great mass of blood which it pumps through every minute. A coronary thrombosis is the name for the sudden clotting of the blood in one or more of the special cardiac blood vessels, the supply of nourishment to a part of the muscle being thus arrested.

ENZYME: A general term for certain protein chemicals produced by living cells and capable of bringing about various chemical reactions, though present only in traces. They are the parts of digestive juices which break up and dissolve the fat, starch and meat of food; they are also responsible for fermentation: the word 'enzyme' in fact means merely 'in yeast.'

PELLAGRA: A disease in which the chief symptoms are diarrhoea, a peculiar symmetrical dermatitis (inflammation of the skin) and often mental changes (dementia), the whole being curable by a suitable nutrition.

PHLEBITIS: Inflammation of the walls of veins, often associated with the clotting of blood in the vein, near the damage.

SACCHARIMETER: An instrument for measuring the amount of sugar in a solution, usually through the measurement of some simple physical property of sugar, such as its power to rotate the plane of polarisation of polarised light.

Our Contributors

G. W. Scott Blair was born in 1902. He is now Head of the Chemistry Department at the National Institute for Research in Dairying, but his own research is more concerned with physics than with chemistry. Previously he was at the Rothamsted Experimental Station studying the physical properties of soils, flour dough, honey and other materials connected with agriculture. In 1929-30 he held a Rockefeller Fellowship at Cornell University, where he studied the plasticity of potters' clays. He has written two books on rheology, the study of the flow and deformation of materials.

A. W. Haslett is a Cambridge graduate, who has made scientific journalism his career. He is the Editor of *Science To-day*, and author of a number of books of which *Science in Transition* has lately been recommended by the Book Society.

Gabriele Rabel, of Vienna, studied Physics and Biology at Vienna, Leipzig and Berlin. Author of various publications on the history of science including a book on *Goethe and Kant*.

D. A. Spencer is a Past President of the Royal Photographic Society (1935-36) and before the war was a Consulting Chemist and Managing Director of Colour Photographs Limited, a firm that, until the outbreak of war, supplied to British commercial photographers the majority of the colour photographs used in advertising illustrations; joined the Kodak organisation at the outbreak of war, and was loaned to the Royal Aircraft Establishment, Farnborough, subsequently becoming Principal Scientific Officer in charge of research and development on Air Photography in the Ministry of Aircraft Production. After the war, returned to the Kodak organisation, and is now Technical Adviser to the Kodak Organisation. Education: Wyggeston Grammar School, Leicester, and Royal College of Science, London.

Oliver Graham Sutton is Bashforth Professor of Mathematical Physics at the Military College of Science, Shrivenham, Wilts. He left university teaching to join the Meteorological Office in 1928. Engaged on research work on turbulence in the lower atmosphere. During the war was successively Superintendent of Research at the Chemical Warfare Experimental Station, Superintendent at the Tank Armament Research Establishment, Chief Superintendent of the Radar Research and Development Establishment, Malvern, Worcs. He is married and has two sons.

John Yudkin was born in London in 1910. He graduated in chemistry at London University in 1929 and in biochemistry at Cambridge in 1931. He spent the next twelve years at Cambridge, where he was engaged in research in biochemistry and nutrition. In his spare time, he qualified in medicine, taught physiology and was Director of Medical Studies at Christ's College. He spent three years in the R.A.M.C., part of it in West Africa, where he managed to do some further research on nutrition and also on malaria. In 1945, he was appointed to the Chair of Physiology at King's College of Household and Social Science (University of London) where he is continuing his nutritional research. His wife comes from South Africa and they have two sons.

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Editorial

FACTS, and more facts! cry the laboratory scientists, banging their fists with approval on the bench, and jolting some apparatus in course of construction. But what's their significance? say the natural philosophers, looking up from their desks, leaving the mixture of doodles and speculations scribbled on the paper before them. And the two groups eye one another with suspicion and mistrust. Which camp you work in is a matter of temperament, and the sad truth is that so few are capable of work in both. Yet both are essential to the progress of science. All the time, the experimenter is battered by a flood of inchoate sensations arriving simultaneously through all his senses to his brain: how shall he select the significant, direct his powers of concentration and interpretation, except by reference to some theory previously acquired, and now perhaps so completely absorbed as to be a part of the unquestioned dogma of his everyday life?

Ideas we must have, and without them facts are nonsense. But ideas, like practical methods, are best out in the open, where everyone can see them for what they are, with their little invalid assumptions and shoddinesses. It is our faith and our policy to emphasize the thought over the fact in the fields of science our articles review, and we shall do this more and more in later issues. In this way we hope not merely to provide a mental map on which the factual details can later be inscribed, but further to stimulate the progress of Science itself by drawing attention to ideas of one speciality which may find a use in another, unrelated to it, for often a single new intellectual approach proves fruitful over a wide area.

This issue opens with an account of how the archæologist goes to work, and closes appropriately with a study of that

subject which has made our culture materially so different from the preceding Stone Ages—Metals and Alloys. Dr Fox, in an article which repays careful study, discusses the underlying principles in the production of alloys, and the problems of modern metallurgical research. His essay can be profitably read with the article on Metals by Sir Lawrence Bragg which appeared in our first issue. In *What the Earth is Made of*, Lieut.-Colonel Tillotson excavates a good deal deeper than the ten feet or so of surface soil which interests the prehistorian, and describes how earthquakes and artificial explosions are used to probe the composition of the underlying strata: and to search for oil. Mr Haslett discusses the origins of Coral Islands, and the light thrown on this problem by recent excavation, in his Research Report. *Viscosity*, by Dr Bell, is an elementary introduction to the modern conception of the liquid state, which is exemplified also in a note on *Glass*. *Group Psychotherapy* explains the general approach in the psychological treatment of neurosis. *Demography, Science and Administration* is a critical discussion of the study of population and its vast importance for modern government, which can only apply controls successfully to a society whose size and composition are known. Throughout, our contributors are striving to give a critical, balanced account, to reveal how the new 'facts' were obtained and what their significance is taken to be. We want to offer something more valuable than knowledge, and that is Understanding.

Scientific Prehistory

I. W. CORNWALL

What is Prehistory?

WRITTEN records of the past are the raw material of History – but what of the long career of mankind before writing was invented? That is the field of the science of Prehistory. In the Near East writings are found from as early as about 4000 years B.C., but in Britain Julius Cæsar's account of the first Roman invasion brings *our* prehistoric period to an end as late as 55 B.C.

The prehistorian compiles his account from the traces left of their lives and activities by peoples without writing. His principal helper is Archæology, the science which studies human culture through its material equipment, but, especially for the earlier part of man's story, many other sciences have an important contribution to make.

In this sense, palæontology and geology are the handmaids of Prehistory. They enable us to discover something of the biological origins of the human race and of the nature of the world in which the earliest men lived, their way of life and relation to their environment. Another contributor is comparative anatomy, which concerns itself with their rare skeletal remains and gives us some account of their forms and faces. Archæology takes a hand when their practically indestructible stone implements are in evidence and becomes the principal instrument in exploring the later periods, when, with advancing material culture, remains of the homes, villages, cemeteries, tools, weapons, ornaments and so on of ancient man become available for examination.

Many of the rarest and most instructive relics of man's remote past, such as skulls, bones and stone implements, have been discovered by chance when digging foundations

for buildings, levelling roads or working gravel. Many others must have passed, unnoticed and unrecorded by science, into concrete-mixers and brick-kilns. Some few have been saved from a similar fate by the devoted vigilance of enthusiasts and the co-operation of managers, foremen and labourers.

Most prehistoric material, however, has been obtained by systematic excavation, in places where some chance discovery has shown the presence of ancient remains or where actual evidence of man's occupation or activities can still be discerned at the surface.

Having assembled his finds, the prehistorian cleans, repairs, reconstructs and studies them, trying to extort, from the objects themselves and the circumstances in which they were found, every piece of information which they can yield as to their nature, use, method of manufacture, how they came to be where they were found, what sort of men made or owned them. By comparison with similar specimens already known quite a detailed picture of the persons, the world and the lives of an ancient people can be compiled.

The work is not finished until it is published, so that not only conclusions, but the evidence itself and the argument leading to the conclusions, are available to anybody interested. In digging up a site the excavator has destroyed the text of an ancient document. The finds are only illustrations to it. Nobody can ever again read what it contained unless he reconstructs the site in a publication, describing every detail observed in the field, whether he has understood its meaning or not. As knowledge advances, in the future, it may easily be found that his conclusions were quite mistaken, but, if the facts are all there, better-informed prehistorians may be able to give a more accurate interpretation.

What the prehistorian finds – and what he doesn't!

Let us imagine a relatively advanced prehistoric homestead, such as Little Woodbury (Plate 9), of the immediately

pre-Roman Early Iron Age. If the place was merely abandoned and left to rot, hardly anything of use to the inhabitants would be left behind, but we should still be able to glean something from the rubbish. If, on the other hand, it was suddenly destroyed, as by fire, a great many objects of interest to us might escape the eyes of the salvagers and remain, buried in the ashes, to be revealed by the excavator.

The steading was, perhaps, surrounded by an earthwork or a stockade. We should find the bank and ditch, or the post-holes, identify the gateway, the stock-corral, the granary and the store-pits. These last would contain a certain amount of interesting remains – discarded fragments of tools, utensils and finery, along with the usual household and farmyard rubbish. The house was probably of wood,

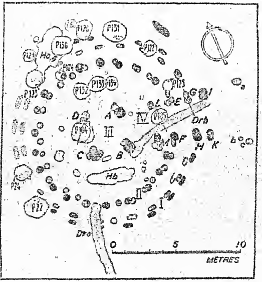


Fig. 1.—Plan of post-holes, pits and drains of an Early Iron Age house at Little Woodbury, Wilts. The post-holes shown in full black represent those of the latest reconstruction, replacing those shaded, of earlier date.

(Bersu: Excavations at Little Woodbury, Wilts. Proceedings of the Prehistoric Society, 1940.)

with a thatched roof, of which only the post-holes or charred stumps of the timbers would remain. There may

have been wattle hurdling daubed with clay for the walls. If this had been burnt the impression of the hurdle might be left for us to find. Of course there would be pottery, but many of the other household fittings and utensils must have been of wood. All this, with basketry and woven textiles, would perish, but clay or stone spindle-whorls and loom-weights would survive to testify to the manufacture and use of textiles. Nothing made of hide, horn, sinew or gut – all useful primitive materials – would remain, but bone and deer-antler implements might be preserved – blade-bone shovels and antler-picks, pins, weaving-combs, etc. – and even, perhaps, much-corroded iron tools – axes and bill-hooks. The rest of the farm implements, mostly of wood, must have rotted. Of clothing we would find only bone or metal fittings and ornaments – pierced animal-teeth, shells and beads for stringing, bronze brooches and so on. Sling-stones, flint arrowheads and metal weapons may have survived; of food, only the meat-bones and perhaps carbonized grains of corn.

In peat-bogs and other waterlogged deposits, objects of wood, basketry, textiles, leather, grains, fruits and seeds are occasionally preserved to give us a glimpse of how much is generally lost (Plate 13).

For still earlier times, when men lived in caves or in the open and had a much scantier equipment than this, there is even less to show – flint and other stone implements, bone tools, meat-bones and, perhaps, a few pierced teeth, shells and other ornaments. Even pottery, the standby of the later periods, is lacking, but the caves have yielded clay-modelled animal figures and pictures, chiefly of animals, engraved, carved and painted on the walls.

What is a 'dig' and how is it done?

(a) Where to dig.

The flint hand-axes and flakes of the earliest men, and their very rare bones, are generally found by chance in commercial excavations — gravel-, sand- and clay-pits, and,

occasionally, in limestone quarries which expose the filling of ancient caves. The bones of extinct and still-surviving species of animals among which they lived are found in the same places. This stage was the Old Stone Age or Palæolithic period. In the later part of it the climate of what is now temperate Europe became almost arctic at times. Mankind took to caves in limestone rocks and over-hanging shelters (Plate 8), and it is in, and in front of, these places that their tools, animal bones, wall-paintings and, sometimes, their own remains are found.

Later, forests covered most of the land. Middle Stone Age, or Mesolithic, men lived in the more open places – sea- and lake-beaches, in fens and bogs and on sandy wastes. Mounds of shells and rubbish, the waste from their beachcombing and hunting, yield evidence of their way of life, as well as their tools and sometimes their skeletons.

Soon we find the first settled communities tilling the soil, stock-rearing and (most important for us) using pottery. Their settlements are found on the open Chalk downs and hill-tops, associated with the long barrows, cairns and chambers of huge stones which they built as communal tombs (Plate 2).

Round barrows and other circular monuments, such as Stonehenge, belong to the Bronze Age, though it is likely that some of them, at least, continued to be used and venerated up to historic times. There are also cemeteries of cremated burials in pottery urns, of the later Bronze Age. Only very few settlements of these people are known. Apart from their graves and temples, chance-found 'hoards' of bronzes, probably the stock-in-trade of travelling smiths, tell us almost all we know of Bronze-Age equipment in this country.

Many commanding hill-tops are crowned with forts and earthworks dating from the Early Iron Age (Plate 3). We also know some habitation-sites and widespread field-systems of the time. The latter are often marked by

'lynchets' – banks of earth formed by the gradual downward creep of ploughed soil on the hillsides.

Prehistoric sites may show on the surface as mounds and depressions, save where the plough has levelled them. Even so, their presence is often revealed in air-photographs (Plates 6 and 19) by differences in colour of the crops: dark where the soil is deeply disturbed; light where walls and impervious structures are only thinly covered.

Two of the newer methods of plotting the limits or layout of an ancient site are resistivity-surveying and phosphate-determinations. The former relies on difference in electrical resistance between disturbed and undisturbed subsoil; the latter on the phosphate-content of soil-samples from different parts of the site – greatest where human occupation has been most intensive and continued.

(*b*) *How to dig.*

When the excavator takes out his first trench on a 'dig,' he is opening a volume with four dimensions – three in space and one in time. What he finds may be compared with the torn-up shreds of a document from a rubbish-heap. Certainly more than half the pieces are missing and the ink has run on those that are left.

No man can be his own expert in every scientific speciality which touches Prehistory. Like a detective, the excavator co-opts expert witnesses to examine and report on his finds and uses their conclusions to help him to construct a coherent story. He must be able to recognize, in the field, what may be worth submitting to one of his specialists, and, to that extent, he must know a little of the methods and limitations of the sciences concerned.

Before digging can begin, there must be a detailed survey and recording by scale-plans and photographs of the site as it is. Trenches are then laid out to cut through, at right angles, and explore in section, any visible structure that seems interesting – mounds, banks, ditches or the lines of walls (Plate 10). The trenches are taken in stages down

to the 'natural,' the surface of the ground as it existed before any human occupation. The work is mostly done, not with the traditional 'spade' but with a pointing-trowel or other small hand-tool, as soon as an undisturbed layer is reached. Thus nothing important is disturbed or broken, but carefully cleared from the surrounding earth, so that it may be seen and recorded in its original position. The most delicate work, as in the cleaning of a fragile skeleton, may even be finally touched up with a needle-point and camel-hair brush (Plate 11). Every crumb of soil is sifted or broken up by hand to avoid loss of even the smallest piece of evidence, such as a bead.

A close watch is kept all the time for changes in character or archæological content of the deposit, so that finds from every distinct level may be kept separate.

When the exploratory part of the dig is complete, the excavator should be able to link up the sections exposed by his trenches and form an idea of the extent, lay-out and nature of the structures involved. If time and funds permit, the site, or a part of it, may be systematically cleared in strips or squares, exposing ancient surfaces layer by layer, down to the 'natural.' A skeleton of earth-balks is left standing up to the last moment, as a control on the stratification (Plate 1).

Disturbances are recognized, their limits defined and cleared out before undisturbed layers with their contents are touched. These are the really valuable, authentic, documents.

Every fact, understood or not, is recorded. Its explanation may emerge later in the dig, or it may not be found for years, in connection with quite another excavation.

Throughout, scrupulous cleanliness and tidiness are observed – the lines of all trenches straight, the sides vertical, the excavated soil thrown well back, or even barrowed right off the site to a dump out of the way. Only in this way can every pertinent detail be observed and recorded.

These principles apply to every dig and every archæological period, with variations in plan of action for particular cases. A round barrow, or other circular structure, may be excavated a quadrant at a time (Plate 7); an area such as a cave-floor or an ancient land-surface, without visible structures, by arbitrary squares; the line of a wall or ditch plotted by short transverse trenches at definite intervals.

Interesting details, such as burials and groups of pottery or post-holes denoting wooden buildings, hearths and so on, are carefully cleaned and recorded in place, with every associated object, before anything is moved.

Finally, the dig is filled in and levelled off.

How the fieldwork is recorded and what the excavator takes home.

Of no less importance than the actual digging is the recording in the field. The field-notebook contains a day-to-day account, with detailed small scale-plans and sections, of the work as it is actually done. Trenches or areas, and each distinct level in them, receive identifying symbols. Finds in them are individually or collectively marked with their appropriate locations and a reference to the page of the notebook on which their discovery is recorded. Objects other than pottery may be entered on cards with serial numbers, each with a rough drawing, measurements and description and all the relevant information as to its original situation and position.

Pottery, which may be very plentiful on later sites, is washed, sorted and selected on the site. Much of it may consist of small undistinguished sherds belonging to a common and well-known type. Once enough types have been selected, establishing every characteristic variety of ware, pot-form, finish and decoration found on the site, the rest may be discarded and re-buried when the dig is filled in. In this way careless disposal of unwanted fragments will not complicate future excavations anywhere else. Of any group of sherds which seem likely to have formed a

single vessel every one is kept, in the hope that the pot may be rebuilt or at least its shape recovered.

Photography at every stage saves pages of description in the eventual publication. More important: it is *prima facie* evidence of the original appearance of structures and objects which may have had to be moved or destroyed as the dig proceeded. Archæological photography is a special art, beset with snags and limitations. It is well to be sure that a good negative has been obtained before the irreplaceable subject is demolished.

Samples of shells, bones, soils from the different layers, peat, charcoal, rocks and minerals (in the case of geological deposits), food-grains and industrial waste (e.g. metal-slag) may help, after examination, to fill in the picture given by the other finds. They are best taken in person by the expert who will examine them.

Deciphering the story told by the finds.

(1) *The study of types.*

Ancient man was bound by tradition, and successive generations tended to reproduce the types of implements, pottery, and so on used by their forbears. Changes, both of evolution and degeneration, took place by degrees insensible in any one lifetime. The archæologist, therefore, bases many of his conclusions on similarities, and the indicated relationships, between known types and the particular objects he is studying. A whole assemblage of characters, common to the culture at his site and sites known elsewhere, is even more convincing evidence of relationship. Thus, a particular group of people buried their dead in a crouched attitude in round barrows, used winged-and-tanged arrowheads of flint and placed with each body a clay beaker of characteristic form with a peculiar style of comb-impressed decoration (Plate 12). This assemblage, when found at two widely-separated places, establishes a close relationship. We do, in fact, recognize the 'Beaker-Folk' of the early Bronze Age by this

constant assemblage of characters. Their remains are found all over Western, and a part of Central, Europe.

It seems as if at least the more momentous discoveries of prehistoric times – of the bow and arrow, of agriculture, of the wheel and so on – took place only once and in one region, being thence diffused by migration, trade and contact between adjacent peoples. Evidence for the contrary process of independent development, at several different

Fig. 2.—Distribution—map of gold 'lunulae' (crescent-shaped neck ornaments) of the Early Bronze Age, showing their Irish origin, outlying occurrences and predominantly maritime distribution.
(Fox: The Personality of Britain. Nat. Museum of Wales, 1943.)

centres and times, is much more scanty, but cannot be disregarded as a possibility in certain cases.

A sudden cultural break at a site, therefore, indicates outside influences at work. This is seen by the excavator as a sharp distinction between the cultural contents of one layer and the next above it. It may not be obvious, consisting, perhaps, only of a change in the occurrence or character of a single class of objects, but when it is found it is highly significant.

(2) *Distribution.*

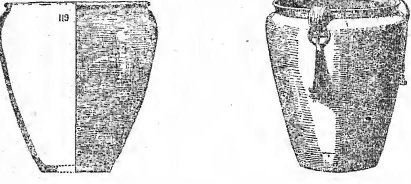
If the new element is already known at other sites and in other regions, the investigator will consult, or construct, a map of the distribution of that and allied objects. The map may show the greatest concentration of the foreign element in a particular region, with outlying occurrences along natural routes linking it with his area (Figs. 2 and 5). In this case the prehistorian may conclude that he has discovered the source of his intrusive objects, or, at least, of their inspiration (for they may not be identical with the originals). According to the degree of resemblance and numbers of objects involved, he must decide, perhaps with the aid of statistics, whether his finds are sporadic imports, local copies of such imports (Fig. 3) or the property of an actual body of migrants or invaders from the parent region.

Objects themselves betray something of the way of life of their owners. Hoes and sickles point to agriculture, axes and adzes to wood-working, querns to the grinding of cereals, swords to war and conquest. If discarded bones are all those of wild animals it is to be inferred that the people in question hunted, but did not rear, their meat.

(3) *Specialist reports.*

These may add very sensibly to our information. Here is an instructive example of what the palæontologist can contribute to Prehistory.

W. Soergel studied animal bones from several sites in



A B

Fig. 3.—A typical Early Iron Age household pot from Maiden Castle, Dorset and a bronze 'situla' or bucket from N. Italy, of which the former is a debased form, translated from metal into clay.
(A. from Wheeler: Maiden Castle. Soc. of Antiquaries, London, 1940. B. from Déchelette: Manuel d'Archéologie préhistorique, A. & J. Picard, Paris, 1908.)

Germany, at some of which implements and actual remains of Palæolithic man had been discovered. He found that his sites fell into two well-defined groups, in one of which a third to a quarter of the remains of elephants belonged to young beasts less than 6 years old. In the other group older animals predominated, some two-thirds being over 50 years old and none under 6. Now the first group included all the sites at which man was known to have been living, as well as two, showing a small proportion of young animals, where there was no evidence, at that time, of his presence. Soergel concluded that, in those places, man had hunted the inexperienced members of the herds, for nothing would otherwise account for the difference in age-distribution. Further support for this theory came some years later, when a human skull was found at Steinheim, one of his two anomalous sites. The other remains a blank, but we look forward hopefully to hearing, one day, that the presence of man has been proved there also.

To-day we associate elephants, rhinoceroses and lions with tropical regions. The deposits just described show that

they were also numerous in western Europe when the men of the early Old Stone Age were living, though the climate

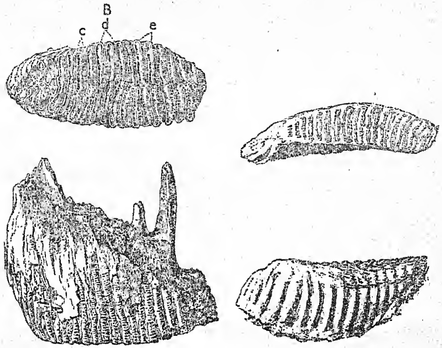


Fig. 4.—Elephant-teeth. On the left, two views of an upper molar of the Mammoth (*Elephas primigenius*), whose presence in a geological deposit denotes a cold climate for its formation. On the right corresponding views of a lower molar of *Elephas antiquus*, which lived in a temperate or warm climate.
From Zittel's Textbook of Palæontology, Macmillan.

was not very different from that of our day (Fig. 4). On the other hand, arctic conditions are indicated by the remains of reindeer, lemmings and arctic foxes from the cave-earths of southern France, belonging to later stages of the same cultural period.

Nor are bones the only indicators of climate. Sea and freshwater shells and land-snails can indicate fluctuations far less extreme than these. A few degrees of change in average annual temperature or sea-salinity, a few inches difference in rainfall, will be reflected by alterations perceptible to the conchologist in the relative numbers of the

species composing the molluscan faunas of beaches, river flood-loams and field-ditches.

The botanist is another specialist whose help is often required by the prehistorian. He can determine the species of trees and bushes from sizeable fragments of charcoal in the hearths of prehistoric sites. Quite a full picture can be made in this way of the local vegetation of the time. In a peat or a lake-silt the very wood of piles or wattle-work may be preserved for him to determine. Even wind-borne pollen of trees and plants, preserved in such conditions, can be identified under the microscope. Pollen-analysis of a level in a peat showing the presence only of pine and birch woods suggests a climate colder, at least in winter, than one with oak, elm, lime and other deciduous forest trees. This method is now being extended to include the pollen of herbs and grasses as well as of trees.

The botanist may also be able to trace, from a few carbonized grains or a grain-impression in the once-plastic clay of a pot, something of the story of prehistoric cultivated wheats and the travels of the men who sowed and reaped them.

The composite picture of animals and plants contemporary with early man may be of importance in dating, at least for the earlier periods of prehistory.

Apart from the palæontologist and the botanist, the help of the expert on soils is often needed. In later times, climate and surroundings were not very different from what they are to-day, but the soil-scientist can recognize a 'fossil' turf-surface in the section of an Iron-Age rampart which has been reconstructed in antiquity (Plate 4) as readily as he does the weathering in a boulder-clay or loess due to some thousands of years of exposure.

The petrologist may be able to say where the characteristic stone for a particular 'polished' Neolithic axe originated. That of an axe found in Hampshire must have been quarried at a particular place in Cornwall. Axes of a rock from the Lake District have been found near Barrow-in-

Furness, Birmingham, in Northamptonshire, Buckinghamshire, Surrey, Wiltshire and near Gloucester. The unavoidable inference as to the widespread ramifications of trade

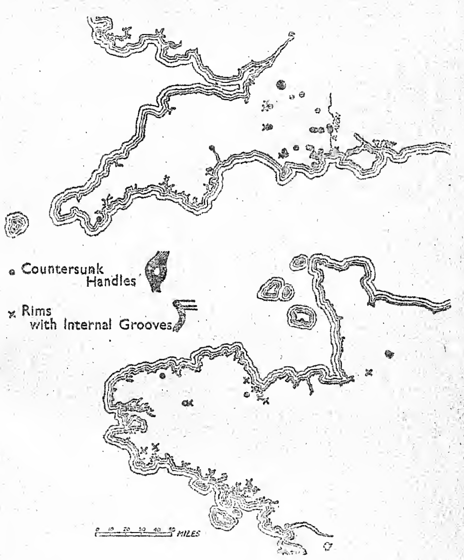


Fig. 5.—Distribution map of Early Iron Age countersunk pot-handles and internally-grooved rims, showing Breton cultural affinities and the probable points of entry into Britain with the concentration of the immigrants in Hants and Wilts.

(Wheeler: Maiden Castle. Soc. of Antiquaries of London. 1940.)

and exchange, even in Neolithic times, is most striking.

Similarly, the chemist may determine, from the composition of a far-travelled amber bead, whether it originated in East Prussia or Sicily. A mineralogist may be able to decide, from traces of characteristic impurities present, the particular ore-deposit from which the metal of a Bronze-Age spear was smelted. The student of animal bones can help to unravel the history of domestication in animals. Working with the human remains, the anatomist and physical anthropologist seek to define the racial affinities of the people concerned.

Experts' reports on materials from any one excavation are not always impressive or abounding with spectacular results. Now and again, one of them may, however, be able to say that, to the best of his knowledge, a particular object or material from a British site could only have come from (say) the Rhineland. At once a connection of some kind is set up between two remote prehistoric peoples, of which the importance to the prehistorian may prove to be very great. It is worth many inconclusive investigations to obtain even one such informative result.

How long ago was it?

Archæological deposits consist mainly of the rubbish of human occupation and have slowly accumulated where they lie, often in more or less distinct layers. *Provided that there has been no later disturbance*, it follows that what is found deep down must be earlier than what lies above it. Very often, however, there *has* been some disturbance – as when later occupants dug pits or wall-foundations into earlier rubbish, or when rabbits and badgers have been active. If we find, say, a Roman coin in the same layer as Neolithic pottery, there is only one possible conclusion: that the deposit has been disturbed and mixed, perhaps as early as Roman times, possibly only quite recently. Certainly the pottery is not in its original context. The latest datable object dates the layer in which it is found. If, however, we

find the same New Stone Age pottery in a layer including nothing demonstrably later in date, we may be reasonably certain that we are in a stratum which has lain undisturbed since the time when that sort of pottery was being made and used. The same stratigraphic principle (derived, of course, from geology), applies to Old Stone Age relics in geological, not humanly-formed, deposits. This principle gives us a *relative chronology:* the bare order in which prehistoric events occurred.

Within the last ten years or so, geology has developed tentative *absolute time-scales* – dating in years.

One of them is based on the known extremely slow rates of decomposition of traces of radioactive substances present in rocks and minerals. This dates the earlier geological periods.

Prehistory is, of course, only seriously concerned with the Pleistocene and Recent periods of the geologists, comprising, perhaps, the last million years of the Earth's estimated age of 3,000 million. The sub-human ancestors of man must have been in existence before this, but the first undoubted men known to us belong to the early part of the Pleistocene, say 600,000 years ago.

Working on geological evidence in the Alpine region, Penck and Brückner constructed a curve to show the growth and retreat of four main Pleistocene glaciations and to indicate their probable duration and extent.

Now, astronomers, for their own purposes, have calculated for the last million years the effect, on the amount of solar radiation received at the Earth's surface, of cyclic changes in the complicated motions of our globe. Some geologists interested in the Pleistocene Ice Ages have noted a degree of correspondence between these results and their own which seems to exceed that attributable to pure chance, on a basis of mathematical probability. Assuming some connection, therefore, but without attempting to define it, they have provisionally correlated the more detailed 'radiation-curve' and its time-scale with the glaciation-curve

(Fig. 6). The absolute durations and intensities of glaciation, and of the interglacial periods, indicated in this way, prove to be of much the same order as that suggested by Penck and Brückner on purely geological grounds. We thus obtain dates for the main events of the Pleistocene which, if not yet very accurate, are at least valuable working hypotheses and probably of the right order of magnitude.

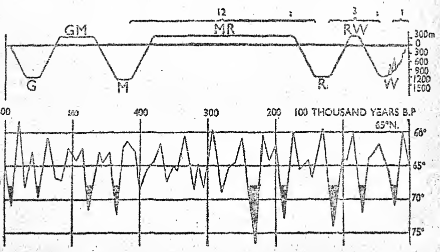


Fig. 6.—Glaciation- and radiation-curve. The upper curve is that of Penck. The axis represents the level of the present Alpine snowline with graduations above and below it in metres. The dips in the curve correspond to the four Alpine glaciations, Günz, Mindel, Riss and Würm (marked by their initial letters); the peaks to the Günz-Mindel, Mindel-Riss and Riss-Würm interglacial periods. From the degree of weathering of the glacial deposits, Penck estimated that, taking post-glacial time as unity, the Riss-Würm amounted to a period 3 times as long, Mindel-Riss being 12 times as long.

The lower curve is the radiation-curve calculated by Milankovitch in 1939. In shows, on an absolute time-scale, the variations in solar radiation received at Lat. 65°N. during the last 600,000 years. The four groups of minima shown in full black are regarded by some geologists as corresponding with Penck's four glaciations. In this case, three of them are seen to have been double and the last triple. Recent field-work tends to corroborate this theoretical multiplicity of the glaciations.

(Penck's curve re-drawn from W. B. Wright: The Quaternary Ice Age, 2nd ed., Macmillan, 1936. Milankovitch's from Zeuner: The Pleistocene Period, Ray Society, 1945.)

During the last retreat of the ice-sheets, certain banded or 'varved' clays laid down in glacial lakes have been shown to mark the seasons of retreat, by a thick layer formed during summer thaw followed by a thin band during the winter freeze-up (Plate 5). Series of these have been counted and linked up and give reasonably reliable dates for the last 12,000 years. Now, with the varves can be correlated minor climatic phases botanically determined by pollen-analysis. The settlements and implements of pre-historic man are also often accompanied by tree-pollen, so that the dates of the varves can sometimes be transferred to the human cultures.

Finally, we come to the astronomically-fixed calendars and king-lists of the earliest Near Eastern civilizations, which flourished long before western Europe emerged from savagery. Datable objects traded and conveyed thence, when found with prehistoric European remains, afford approximate historic dates for these by synchronism, ample allowance having been made for possible long delay in transit.

A striking example of the method is made possible by the occurrence, in round barrows in Wessex, of segmented faience beads, clearly imported, of which the nearest known parallels were made in Egypt about 1400 B.C. From these we get an approximate absolute fixed point for our Early Bronze Age (Plates 14 and 15).

What do we get out of it?

A great contrast between History and Prehistory is that, while the former is largely concerned with the doings of prominent individuals, Prehistory deals with the daily life of nameless ordinary people. Dynasties and policies have passed unrecorded, but we do begin to know something of the domestic arrangements of the prehistoric peasant-farmer.

Even if the story is tantalizingly incomplete, Prehistory shows something of the evolution of man, of his equipment, economy, society and ideas. Unconsciously, perhaps, but

not less certainly, we compare what we can discern of the life of prehistoric man with our own. If we are tempted to feel a little patronizing towards the achievements of our ancient forbears, we should remember that we deserve no credit for having been born in this century and consider soberly how we, as individuals, might have fared in the conditions of, say, the Old Stone Age.

Once started, knowledge and technology advance, to some extent, by their own momentum. Thus, the astronomer, the atomic physicist and the microscopist, among others, make prehistoric dating possible. Without their equipment and skill, it would still be a matter of pure speculation over most of the field of which we have knowledge.

Even to-day, when education is general and research is a field open to any trained inquirer, there are not very many original minds among our enormous populations. Is it not surprising, therefore, that the invention of so many of our basic economic activities is due to the ingenuity of prehistoric men – among them agriculture, domestication of animals, pottery, spinning, weaving, turning, metallurgy? No one will maintain that the technique of weaving was a chance discovery. Here are the working of brain and hand, the exercise of ingenuity and imagination, at their best. Though the smelting of copper ore was probably discovered by chance, how many of us, seeing a fragment of green malachite amid the glowing charcoal and finding a globule of copper among the next day's cold ashes, would connect the observations and arrive at the conclusions necessary to found thereon a metallurgical industry?

All the superstructure of civilization upon which we pride ourselves is based on some such rare exercise of intellect on the part of a long-dead anonymous artizan. Without such as these, it could never have been erected. Without their heirs, in our time, it may well collapse.

Therefore, better to understand the hothouse civilisation we have built round ourselves, we need to understand the

origins of society – the Old Stone Age family feasting behind its blazing brushwood in the cave-mouth; the Neolithic farmer and his neighbours safe with their brimming grain-pits as the winter sets in; the barbaric Belgic conqueror and his followers, lords of all the South and East of Britain before the Romans came.

History is the connecting link between their times and our own, but it is necessary to trace the devious career of man from his origins up to the opening of history, to obtain the fullest understanding of ourselves.

Eye Grafting To-day

DR MAURICE OUDOT

THERE is no question, in the present state of our techniques, of making a total eye graft, that is to say of replacing a diseased and blind eye by another healthy one to give the patient his sight back. Only a *localised* ocular replacement can be made.

The front part of the eyeball, called the *cornea*, is completely transparent, revealing behind it the black disk of the *pupil* surrounded everywhere by the membrane of the *iris* (See Fig. 7, a sagittal section of the eyeball.) Thanks to this

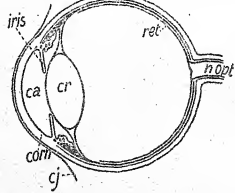


Fig. 7.—A section of the eyeball: front on the left, back on the right. *corn*, cornea; *ca*, anterior chamber; *cr*, lens; *ret*, retina; *n opt*, optic nerve; *cj*, conjunctiva.

transparency, the cornea transmits and refracts the incident light rays and so permits of vision. If, for one cause or another of an accidental or infectious nature, it becomes opaque, the light is blocked, and the sufferer complains of much weakened eyesight. And yet, behind this veil the other media and membranes of the eye remain in good shape and quite fit for the perception of images.

That is why, in those cases, unfortunately so frequent, where local and general medical treatment have failed, the only thing to do is to make a fresh transparency with the help of eye surgery. This problem has been resolved by keratoplasty, or corneal transplantation.

Although in ophthalmic surgery to-day the palm of novelty goes without question to corneal grafting, for all that it is not a recent discovery. Science means patience, and the first trials were made as long as 140 years ago. In this work, we remember abroad the names of Van Hippel, inventor of the trephine for detaching discs of corneal tissue, of Salzer, of Fuchs, of Elschnig, of Nizetic, of Imre, protagonists of new techniques, and especially the name of Filatov, who created and organised a specialised Institute for Keratoplasty at Odessa in 1927. America came into the field later, but with the immense resources at her disposal, and the drive of Elschnig's pupils, who had emigrated, she has largely made up her leeway and floods us with her publicity. On the other hand, in France for instance, in spite of the early attempts of Magitot, which go back to 1913, the operation remained a Congress curiosity for a very long time.

But a few years ago, just before the 1939-45 war, efforts increased. The Lyons school, in particular, in contact with Central Europe through the intermediacy of Switzerland, became interested and excited by the new techniques; and already, French experts such as Sourdille believe on the basis of their personal experience that the corneal graft is now a field for practical surgery, and that very probably the next few years will see operations of this kind on the increase. Theoretically, intervention is very simple. One removes an opaque segment of cornea and replaces it by a transparent piece from a healthy eye.

The *graft* is the portion of transparent cornea which will replace the opaque section of the diseased eye. It can be taken from an eye which has had to be removed from a patient for some other reason. But all authors agree in preferring a graft taken from the eye of a corpse. Enuclea-

tion of the eyeball must be made as soon as possible after death, in the first twelve hours. It is then kept in a cold room 24 hours or more, preserving it in the future recipient's blood with every desirable aseptic precaution. Unfortunately in some countries laws forbid any interference with a dead body until 24 hours after the death has been registered. This must be modified as soon as possible because of the obvious social importance of the operation.

The Americans, with that sense of size, organisation and publicity peculiar to them, have conceived of the creation of a special bureau to supply the necessary material: 'The Eye Bank for Light Restoration.' To this agency (in New York) come those who will have to have an eye removed, to offer themselves for a future corneal transplantation. Furthermore, a great publicity campaign has been undertaken to encourage people of every race and all ages to leave their eyes to the bureau in their wills. They will be examined, and tested to confirm the possibilities of future use. Recently, to the original collecting centre has been added a teaching centre which gives every ophthalmic surgeon the opportunity to educate himself in the technique of operation. In the course of its first year's functioning this body has responded to more than 3,000 requests. Without going to the full length of such an organisation, which makes us smile a little, we would find it worthwhile to collect together offers and requests for corneal transplantation.

Operative technique.

The graft can be penetrating or non-penetrating, total or partial, according as it involves all the thickness of the cornea or not, and all its surface up to the limbus (periphery of the cornea) or only a limited segment of that surface. We cannot for the moment make a success of a total graft for the whole of an opaque cornea. Actually the most frequently practised operation is a transplantation partial as regards surface – limited to a central zone 4 to 5 mm. diameter, corresponding to the visual area of the cornea;

and *total in thickness* – involving all layers of the cornea; whence the name of partial penetrating graft.

Like the type of graft, the technique of implantation itself varies from author to author. We shall borrow the description of the Swiss masters, notably Franceschetti and Streiff, who have a following in France. We must consider in turn:

1. The preparation of the patient.
2. Cutting the graft.
3. Placing the graft on the diseased eye, and keeping it in place.
4. Post-operative care.

1. *Preparation of the patient.*

A penetrating graft always requires the most minute preparation of the recipient's eye. As well as the cases where, before the actual grafting, it is necessary to make a number of preparatory operations (for which the ophthalmologist alone can judge the need), in favourable cases also, where grafting is the one and only operation it is still very important to insist on a whole series of preventive measures.

From the first, perfect asepsis of the whole region is essential. The instillation of penicillin drops will thus be very valuable. Anæsthesia will be obtained with cocaine drops, and especially by the injection behind the eye of an anæsthetic solution of syncaine, a compound allied to

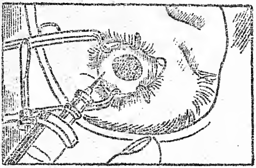


Fig. 8.—While the eyelids are held open by the retractor, local anaesthetic is injected into the eyeball. This is the left eye: note the nose on the right of the diagram, and the eyebrow below.

novocaine. Neighbouring parts (eyelids, skin) are likewise locally anæsthetised. Finally, two horizontal and two

vertical threads are stitched across the eye so that they cross and form a tiny square. At first they are left slack, but later when the graft has been put in place they are tightened and then form a little trellis to hold the graft in place. As for the risk of a rapid rise in pressure of the intraocular fluids after the operation, it is avoided by drops which lower the tension of the eyeball (eserine, etc.).

2. *Cutting the graft.*

Whether one uses a graft from the dead or one from the living, it is detached for preference from the enucleated eyeball: for this a trephine is used, a kind of tube with a very sharp end, the punch-movement of which is limited to about 1 mm., which corresponds to the usual thickness of

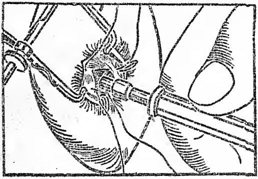


Fig. 9.—The punch removes a disc of opaque cornea.

the cornea. Its diameter varies between 3 and 6 mm. according to the size of corneal disc it is desired to cut, and which is to be taken from the centre of the cornea. Great care must be used in pushing the trepanned disc very gently out of the tube. It is placed on a little spatula, or better, on a flat circular drainer perforated with fine holes, and plunged into a glass dish filled with a physiological fluid or with serum from the future recipient of the graft.

3. *Positioning.*

A trephine with a slightly larger diameter is used on the diseased eye to remove an opaque disc from the centre of the cornea, taking great care to trepan absolutely per-

pendicularly to the iris, so as to obtain a complete section, clean and clear, and to limit the movement of the trephine in depth in order not to wound the lens. This is the most difficult point of the operation. To simplify it, some practitioners make use of a little wooden or metal spatula, which they slide behind the cornea into the anterior chamber of the eye. It then acts both as cutting board and protector.

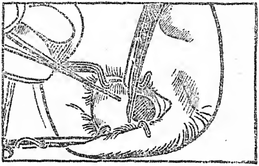


Fig. 10.—Cutting into the anterior chamber with a scalpel (right) to introduce the cutting plate (left).

The quality of the trepanning appears to be one of the essential elements in a successful outcome to the operation. Once the opaque disc is raised, and the bed clear for the graft, it is brought up on its back on a little spatula, slipped into the prepared bed and finds its right position with the help of pats from the spatula.

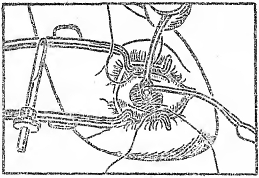


Fig. 11.—The new transparent cornea is lowered into place. Note the two sutures ready in position.

Some surgeons then apply a very fine membrane to the whole extent of the cornea, either eggshell lining or fine sausage skin, the dimensions of which are approximately those of the cornea. Then the threads are tightened (not

too much) in front of this membrane and tied. The whole keeps the graft well in place in a sufficiently firm manner.

Finally the introduction of eserine and penicillin ointment into the conjunctival cul-de-sac and a general grooming of both eyes completes the operation.

4. *Post-operative care.*

The first cleansing does not take place before the sixth day. Only the absence of ocular reactions is then confirmed, without even an examination of the graft. Before replacing the bandage, it is well to instil a few drops of eserine in oil, and a lamella of penicillin.

It is only towards the ninth or tenth day that the sausage membrane and stitches are removed, and one can make sure that the graft has remained properly in place and not become cloudy. If progress continues favourably without complications, the unoperated eye is freed of all bandages on the eleventh day and the patient allowed to get up.

In summary, it is necessary to reckon on about 15 to 20 days stay in hospital, with ten or eleven days immobilised in bed. In spite of undeniable progress in recent years, the operation remains delicate, and the results are not always equal to the trouble expended by both surgeon and patient.

What cases take the graft?

Corneal grafting is not, alas, a panacea, a remedy for all blindness. It is for a certain category of the blind: those with a clouded cornea, whether the opacity is deep or superficial, extensive or localised. The operation can thus be performed in all accidents to the cornea, e.g., burns (quicklime, cement, acid), or ulcers which have become infected and leave a residual speck or leucoma. Patients in whom, following a general infection, the interstitial layers of the cornea have become cloudy, benefit likewise; but because of operative difficulties and the ever-present risk of a hold-up, it seems wise to reserve corneal grafting in actual practice for cases where the specialist judges it to

offer excellent possibilities of improving the patient's vision, without making him run too great an operative risk. It is therefore the ophthalmic surgeon alone, after a complete eye examination, who can make the decision to operate.

Perfect cure, that is to say, regeneration of the corneal nerves into the graft, and its continued transparency, essential conditions for vision, usually require several months of convalescence and periodic examination. It is never guaranteed in advance (see plates 25 and 26).

Some grafts stay clear, others remain translucent, a certain number go wrong, and become cloudy, condemning themselves completely. The most recent figures given by very different authors offer almost identical values. About 20 to 25 per cent of cases are found in which the graft remains transparent, and 30 to 35 per cent translucent. Altogether, in 55 to 60 per cent of cases sight has been improved. These statistics are not miraculous, but they are much more than encouraging and ought to put a stop to sterile scepticism and create a real atmosphere of operative confidence. Step by step as our techniques improve, the percentage of our successes will increase. Let us offer homage to the worth of all pioneers, whatever their nationality, who by their patient labours and their faith have managed to push back the limits of blindness, and by giving sight, have given back hope and the joy of living to so many unfortunate blind people.

(*translated by J. L. Crammer*).

Contact Lenses

FRANK DICKINSON

CONTACT lenses have been 'in the news' again recently. They were worn by a well-known professional footballer, who paid high tribute to their efficiency.

Spectacles, always a handicap in most forms of sport, are being replaced increasingly by the newer types of plastic contact lenses, which enable the sportsman to enjoy normal vision in safety. The footballer featured in the news item is one of many who take advantage of this modern development in optical science.

The basic principle of the contact lens has been known for more than a century. Sir John Herschel, Astronomer Royal, suggested its practicability in 1827. Only in recent years, however, have the more serious limitations of this method been overcome, through experience gained in the fitting of many thousands of lenses in Europe and North America.

The lens is worn in close contact with the sclera (the white portion of the eyeball). It provides a new, optically perfect anterior surface for the cornea, without actually touching the sensitive corneal surface. This clearance of the cornea makes it possible to wear the lens without discomfort. The space between lens and cornea is filled with a fluid similar to the tears.

By means of contact lenses, focal errors of vision may be corrected with a degree of accuracy unequalled, in many instances, by spectacle lenses. This unique feature of 'contacts' is particularly valuable when the cornea has been damaged by disease or injury. In keratoconus, for example (a conical protrusion of the cornea) they offer by far the best means of visual improvement, giving almost miraculous results in many cases previously considered hopeless.

Unfortunately, problems other than those of optical correction obtrude themselves. The fashioning and fitting of the lenses demands a high degree of skill and dexterity. The delicate cornea may be injured by the wearing of an ill-fitting lens, and there are cases in which even a perfect fit fails to bestow the desired degree of comfort. The average period of use at a stretch is still somewhere between five and eight hours.

Perhaps the greatest limitation of the conventional form of lens is the gradual development of a cloudiness of vision similar in effect to that of a smoky atmosphere. The clouding, which begins in most cases after 2½ to 4 hours' use, is believed to be due mainly to the accumulation behind the lens of carbon dioxide, normally exhaled by the cornea into the atmosphere. Recent experiments by Dr Josef Dallos, one of the pioneers of contact lens technique, have proved that clouding can be largely eliminated by the provision of ventilation holes in the scleral portion of the lens.

Several distinctive methods are employed in the fitting of contact lenses. Many recognized authorities favour the moulded lens. The technique consists of the making of an impression of the eyeball, from which a positive cast is prepared, the lens being pressed from sheet plastic to conform to the curvature of the cast. Other practitioners prefer a lens of conical form, designed to fit a limited area of the surface of the eyeball. A much-favoured design in Great Britain is the ground spherical lens, originally introduced by Zeiss. All of these types, which are made from so-called plastic material (synthetic acrylic resin) permit a fluid lens-like zone between the contact lens and the cornea. Another kind of lens is inserted without fluid, being worn in direct, capillary contact with the cornea (see plates 23 and 24).

Although glass lenses are not dangerous, the majority of present-day contact lenses are made from I.C.I. plastic.

The advantages of contact lenses over spectacles include an unrestricted field of vision; security from displacement in sporting activities such as swimming, football and riding;

almost complete invisibility (an undoubted asset in social and stage life) and the visual benefits mentioned above. Among their disadvantages are comparatively higher cost, the limited period of use, and physical unsuitability of the eyes in certain cases.

Demography - Science and Administration

R. R. KUCZYNSKI

1. *The Beginnings of Demography.*

UNTIL ten years ago the word 'demography' was rarely used in this country. Population experts, it is true, had attended the International Congresses for Hygiene and Demography, and they studied the *Aperçus démographiques* published by the International Statistical Institute, but the *Concise Oxford Dictionary* still defined demography as 'statistics of births, diseases, etc., illustrating condition of communities,' while demography, as is evident from the word itself, aims primarily at a description of the population, using, of course, if available, censuses, birth, marriage, death, and migration statistics, and occasionally also statistics of diseases. However, in recent years 'demography' has been used more frequently and more correctly, and the University of London even appointed (in 1938) a Reader in Demography.

Demography, like every other science, has to do with methods and with results. A few scholars have been interested only in the development of methods by which the basic data may be correctly interpreted, and the demographer owes much to those pure mathematicians. Among demographers, who are all, of course, interested in interpreting results, a certain number have contributed to the development of methods.

The first man who ever made a demographic study was the London haberdasher John Graunt. His little book *Natural and Political Observations upon the Bills of Mortality*, published in 1662, was a remarkable achievement. His basic material consisted of the weekly London 'Bills of

Mortality' which showed baptisms by sex and burials by sex, age, and cause of death. He compiled all available Bills and analysed the content of his tables, which covered many decades, most thoroughly and with a vast amount of common sense. He even went so far as to construct a life table for London. This life table, of course, was most primitive and inaccurate – about as inaccurate, I should say, as the recent official life tables for India or for Lagos. His motive for 'deducing so many abstruse, and unexpected inferences out of these poor despised Bills of Mortality' was that 'the Art of Governing, and the true *Politiques*, is how to preserve the Subject in *Peace*, and *Plenty*.'[1] When Graunt published his pamphlet he had not the faintest idea that he had created a new science. Demographic data, he thought, could be useful only to the Administration. 'There seems to be good reason, why the Magistrate should himself take notice of the numbers of Burials, and Christenings, viz., to see, whether the City increase or decrease in people; whether it increase proportionably with the rest of the Nation; whether it be grown big enough, or too big, etc. But why the same should be made known to the People, otherwise than to please them as with a curiosity, I see not.'[2]

Graunt lived in an enlightened period. The great importance of his work was at once recognized both by the State and by Science. His name appears in the original list of Fellows of the Royal Society, which received its charter in 1662, and Sprat, in his History of the Society, speaks of 'the Recommendation which the King himself was pleased to make, of the judicious Author of *the Observations on the Bills of Mortality*: In whose Election, it was so far from being a Prejudice, that he was a Shop-keeper of London; that his Majesty gave this particular Charge to his Society, that if they found any more such Tradesmen, they should be sure to admit them all, without any more ado.'[3]

The original list of Fellows contained also the name of Sir William Petty, who wrote *Essays in Political Arithmetick* and

other demographic studies.[4] An able disciple of his friend Graunt, he was both more knowledgeable and more brilliant, but his contribution to the development of methods was not important. Edmund Halley, on the other hand, who joined the Society a few decades later, was hardly interested in demography as such, and his whole demographic work covers only eighteen printed pages.[5] His great contribution was the discovery (in 1692) of a most ingenious method of constructing a life table. He was not sufficiently explicit as to his data and the use he made of them, and his method has, therefore, been very often misunderstood. Many of his successors in various countries committed grave errors in trying to apply it, while others introduced slight improvements. But in a general way it may be said that Halley's method was for about 175 years the usual device for constructing life tables.

2. *Science and administration.*

England was the cradle of demography, and in the two centuries following the publication of Graunt's *Observations* England's contribution to the new science was equal to that of any other country. But the position has since changed. If a list were made of the hundred best demographers who set out on their careers during the last hundred years, it would be very difficult to find five Englishmen to include in it.

The causes of this stagnation in English demography can be easily discerned. In the first place, the number of people engaged in demographic research (full time or part time) is probably smaller now in relation to the population than it was fifty or a hundred years ago. On the Continent their number has increased by leaps and bounds. In England there is one Registrar-General's Office. On the Continent there are, apart from a Central Statistical Office for each country, numerous State and municipal statistical offices. Moreover, in the Registrar-General's Office priority is given to all matters dealing with registration; in the continental statistical offices population statistics are not at such a disadvan-

tage. A Registrar-General is rightly chosen according to his qualifications to function in this capacity, and he may never have dealt with population statistics before his appointment. On the Continent a civil servant becomes director of a statistical office after having worked for many years either in the same or another statistical office, and it is inconceivable that he be appointed without having had experience in population statistics. It may be argued that the Registrar-General has demographic assistants who are in charge of this section of his office's work. But experience shows that this offers no solution of the problem. The Registrar-General George Graham, in 1879, concluded his last annual report by saying: 'Lastly, I must express to Dr Farr, whom in 1842 I had the good fortune to find here presiding over the Statistical Branch, my grateful acknowledgment of the important services he has ever since continually rendered. He is acknowledged throughout Europe, the United States, East Indies and the Colonies as one of the first statists of the day. To his scientific researches and reports I attribute any reputation that may have accrued to the General Register Office of England and Wales from the time he accepted office in this Department.'[6] All this was perfectly true. Dr Farr, in the Statistical Branch, made the best use of the basic data he got from the Registration Branch. But his efforts to improve those data failed. The birth registration form introduced in 1837, when the Registrar-General's Office was created, was quite defective. From a demographic viewpoint it was much less satisfactory than, for example, the birth registration form introduced in Sweden in 1775. Dr Farr became early aware of that. In his report for 1842 he wrote:

> ... no provision has yet been made for determining the simplest fundamental facts – the foundation of all reasoning on the subject – such as ... the ages of mothers of children ... Upon many of these points the greatest ignorance prevails, writers on population depending on rough approximations derived from scanty, imperfect, and often erroneous data, because the censuses and registers of Europe have not yet been taken and abstracted upon a comprehensive, well-considered plan.[7]

He made similar complaints over and over again. In his report for 1867 he said:

> Two grave defects in the registers of the United Kingdom deprive them of much of their utility as pedigrees, and as records of facts for the solution of the great problems of population. Neither the age of mothers at the births of each of their children, nor the order of birth is recorded; so that the number of children borne by women at different ages, and in the course of their lives, cannot be ascertained. This defect was supplied in the first schedule of the Scotch Act, but the important parts of the schedule were unfortunately discontinued after 1855[8].

It is pathetic to read in the Congress reports of the International Statistical Institute the appeals which Dr Farr made for the registration of the mother's age in all countries keeping birth records.[9] His appeals were not altogether in vain. By 1921 England was practically the only civilized country where this question was not asked. The birth schedule of 1837 remained unchanged until 1938, when Parliament insisted on its reform. If Dr Farr had been Registrar-General – and it was the great disappointment of his life that he was never promoted to this position – the basic demographic data for many decades would have been as ample in England as in the British Dominions, the United States, France, Germany, Austria, Italy, the Scandinavian countries, etc., etc. As he was second in command his country derived only very limited benefits from the last prominent demographer it has produced. That he accomplished as much as he did was due to the fact that he was not only competent but also obsessed by an urge for research and a deep interest in demography. None of his successors combined these qualities.

Another cause of the deterioration of British demography is the lack of contact between administration and science. On the Continent many directors of statistical offices are at the same time university teachers; they sometimes hold seminars in their office and teach the students the whole process of statistical technique. It is quite usual for such students, after they have terminated their university studies, to be appointed assistants and later directors of municipal or other statistical offices, and to become in their turn

university teachers. Nothing of the kind exists in this country. The scholar interested in population problems usually knows very little of the technique of statistical administration; he cannot appraise the technical difficulties and the cost of carrying out the proposals which he may suggest to the administration; he cannot effectively answer the arguments of the civil servant. The administration, on the other hand, focuses its attention on its immediate needs and is, as a rule, reluctant to acknowledge specific legitimate needs of the demographic scholar. This, of course, does not affect the pure mathematician interested in methods but not in results. As a consequence thereof, the foreign reader of a review such as the *Journal of the Royal Statistical Society* must be struck by the high standard of the purely mathematical contributions dealing with a fictitious population, and by the scarcity of demographic papers. The barrier between administration and science deters the British scholar from demographic research; another deterrent is the low standard of the official vital statistics, compelling him to resort to foreign statistics which are difficult to understand without a knowledge of foreign conditions and foreign languages. The general level of demographic doctors' theses submitted to English universities is high, but a demographic study of the authors would probably reveal that comparatively few are born in this country.

3. *English census statistics.*

Censuses have been taken regularly every ten years from 1801 up to 1931. These censuses furnish valuable information to demographers, sociologists, economists, geographers and administrators. I shall deal here only with those data which are of special interest to the demographer. They refer to the sex and age composition of the population, to marital condition, and to fertility. The sex was ascertained from the first census onwards. The ages of the population were obtained in 1821 and again from 1841 onwards. The marital condition was asked for the first time in 1851, and thereafter

at each subsequent census. Questions relating to fertility were put only in 1911.

At the early censuses the omission of persons was apparently frequent, but from 1841 on the censuses in England have probably been as complete as in any other country. This does not mean that the omissions are altogether negligible. There is, for example, a tendency everywhere to leave out young infants, and this tendency is strengthened in England by the habit of delaying the registration of births. Thus the General Report on the 1921 census states:

> It may be observed that the population always comprises a large number of newly born infants whose births have not yet been registered, and that this number may easily have been as high as 50,000 or 60,000 at the date of the census. The attitude of mind which regards such children as not having been placed upon the official roll and not subject, therefore, to the census procedure is an intelligible one ...[10]

It is impossible, of course, to estimate even approximately the numerical importance of the omissions at various ages, but a guess that they aggregate something like one or two per 1,000 of the total population would probably not be far off the mark. They are offset in part by the erroneous inclusion of persons temporarily abroad and by double counting.

While, then, the English censuses may be considered fairly complete, the demographic details are not as accurate as might be expected. The mistakes in the returns on sex, to be sure, are undoubtedly few. But the age data are less satisfactory. There is in England, as everywhere, a tendency to report age in round numbers – that is, in numbers ending with 0. It may suffice to mention that, according to the 1931 census, there were 245,684 men aged 50, but only 215,999 aged 51; 280,182 women aged 50, but only 240,793 aged 51. Ages ending with the digit 7 are unpopular, while there is a marked predilection for ages ending in 8. According to the 1931 census, there were more men and more women aged 58 than aged 57, more men and women aged 48 than aged 47, more men and women aged 38 than 37, etc. That the age statistics of many other countries are not so

defective as those of England is due to the fact that in their census forms they do not ask for the age at the last birthday, but rather for the date of birth. It seems desirable that henceforth England should follow their lead in this respect.

Misstatements of marital condition are also quite frequent. The large excess of married women over married men which appears at every British census can be explained only in part by the fact that the number of married members of the Army, Royal Navy, and Merchant Service who are temporarily abroad exceeds the number of married foreigners who are temporarily in this country and have left their wives at home. It seems that tens of thousands of women report themselves as married though they are not. But a much graver defect is the inadequacy of the statistics of divorced people. Until 1921 all persons over 15 years were asked to state in the census forms whether they were single, married, or widowed. As to divorced persons, it was evidently left to their discretion which of these three alternatives they liked to choose, and if by any chance they were obstinate enough to reveal their actual marital condition they were probably counted as widowed. In 1921 a discreet attempt was made to identify divorced persons. The heading of the column relating to marital condition now read:

For persons aged 15 and over write 'Single,' 'Married,' 'Widowed,' or if marriage dissolved by divorce write 'D'.

The innovation was introduced with great reluctance and with the conviction that it would prove to be a failure. The report states:

At the 1921 census an attempt was made for the first time in this country to ascertain the number of divorced persons in the population ... The total number returned in this category amounted to 16,682 in all, of which 8,464 were males and 8,218 females ... It is greatly to be feared, however, that doubts as to the value of such returns, which were felt and expressed when it was first decided to include the inquiry in the general census questionnaire, have proved only too well founded, for from an examination of the records of the divorces which have been granted year by year, after making full allowance for reductions in the numbers by mortality and by a very high remarriage rate, the

expected numbers might well be put at a figure twice as large as the total recorded above, and it appears more than probable therefore that a large number of persons failed to return the desired information.[11]

The number of men reported as divorced was then slightly greater than the number of women. Since the remarriage rate of divorced men is much higher than that of divorced women, misstatements of marital condition must have been particularly numerous among divorced women. According to the 1931 census the divorced males numbered 13,546 and the divorced females 19,169. It will be interesting to read the official comment on these figures in the General Report, which has not been published as yet.

From a demographic standpoint the 1911 census is still to-day the most valuable of all because it included questions concerning fertility. Each married woman had to state the number of years the present marriage had lasted, the number of children born alive to the present marriage, the number of children still living, and the number of children who had died. The question about the duration of marriage was answered incorrectly by a very large number of wives. The tendency to concentrate on round numbers – 10, 20, 30, 40 – was even more pronounced in the case of marriage duration than in the statement of ages. Moreover, misstatements of short durations were exceedingly numerous. The ratio of couples returned as married 0-1, 1-2, and 2-3 years to the number of marriages concluded in the three years preceding the census was 68, 85, and 89 per cent respectively, the understatement of the number of couples returned as married under one year being mainly due to a desire to conceal ante-nuptial conception. The instruction to return only the children of the present marriage was often disregarded. On the other hand, many mothers seem to have omitted in their statements children who died young.[12]

The first census embodying fertility questions had been taken in 1875 in Massachusetts, and many other countries followed suit. The decline in the birth rate made, of course,

the demand for such enquiries ever more urgent, and between 1920 and 1936 alone fertility censuses were taken in France (1921, 1926, 1931, and 1936), Holland (1920 and 1930), Norway (1920 and 1930), Hungary (1920 and 1930), Estonia (1922 and 1934), Spain (1920 and 1930), Italy (1931), Czechoslovakia (1930), Germany (1933), the Union of South Africa (1921 and 1926), Southern Rhodesia (1921 and 1926), Northern Rhodesia (1921 and 1931), Australia (1921), New Zealand (1921 and 1936). But in this country no such enquiry has been made since 1911.

Another grave defect which must be mentioned in this connection is the date of publication of the English census reports. The fertility enquiry of 1911 was made throughout the United Kingdom. The complete reports for Scotland and Ireland were both published in 1913. For England and Wales a first volume, containing a number of basic tables, was published in 1917; the second volume, containing all other tables and the text, was published in 1923. I have already mentioned that the text volume of the 1931 census is not yet available. The volumes published so far contain merely tables. This, it seems to me, is an intolerable situation which should be remedied and could be remedied easily. I happened to be connected with the United States Census of 1900. The publication of the 1890 census reports had been very slow. But Congress was not willing to run a similar risk again. The Census Act of March 3rd, 1899, provided therefore:

> The only volumes that shall be prepared and published in connection with the Twelfth Census, except the Special Reports hereinafter provided for, shall relate to population, mortality and vital statistics, the products of agriculture, and of manufacturing and mechanical establishments ... and shall be designated as and constitute the Census Reports, which said reports shall be published not later than the first day of July, nineteen hundred and two.

We then had barely two years for the preparation and publication of the reports, not only of a most elaborate population census but also of a most intricate census of agriculture and of manufactures, in a country with a popula-

tion nearly twice that of England and Wales and with an area more than fifty times as large. But we knew that we had to do it, and all the volumes, tables and text, covering nearly 10,000 large, closely printed pages, were published within the prescribed time limit.

4. *English vital statistics.*

Civil registration of births, marriages, and deaths was started on July 1st, 1837. The records are probably as complete as in any other country. Birth registration, to be sure, was somewhat defective prior to the introduction of compulsory registration in 1875, but it is safe to say that nearly all children born thereafter have been registered, though often with great delay. Death registration was almost complete from the outset. Marriage statistics, of course, are absolutely complete, since, while people may be born or may die without being registered, there is no marriage without registration. As to accuracy the vital statistics suffer from defects similar to those of the census statistics. The age at death is too often reported in numbers ending with 0. There is also, at least among middle-aged persons, a predilection for ages ending in the digit 2. Here again the remedy lies in asking for the date of birth instead of the age in years.

Until the new Population (Statistics) Act came into force, the Registrar-General's *Statistical Review* showed merely the number of male and female, legitimate and illegitimate live births and still births, registered in each quarter. From July 1st, 1938, on the *Statistical Review* shows in addition the births by order of birth, age of mother, and duration of marriage. The *Decennial Supplement* gives in addition data about fertility by occupation in the period centring around the census. The *Supplement* dealing with the year 1921 was published in 1927; the volume which is to cover the years 1930 to 1932 is not available as yet. But the records of the father's occupation are not the only ones of which little use has been made. From 1837 on, the registration form recorded the date of birth and the date of registration. But in the

published birth statistics no account (until 1944) was ever taken of the date of birth. We know the number of births registered in a given year, but we do not know the number of births which occurred in that year. According to a statement published year-in year-out in the Registrar-General's *Statistical Review* 'the average time lag between occurrence and registration is usually about a month.' This seems to indicate that the average time lag is usually though not always about a month. But even if the average time lag were always exactly one month, the difference between the number of registered and of actual births might vary considerably from year to year. It may well be, therefore, that even in peacetime the changes in the official birth figures sometimes convey a distorted picture of the actual changes in natality. The number of registered births dropped from 613,972 in 1932, to 580,413 in 1933, and rose again to 597,642 in 1934. The number of registrations in the last quarter of 1933 (129,810) was over 10,000 lower than in any other quarter from 1850 to this day. It is possible, of course, that the number of births was actually as low in the last quarter of 1933 as indicated by the official statistics. But until there is proof to the contrary it seems safer to assume that the drop in the actual number of births in 1933 was smaller than the drop in the number of births registered in that year. The official birth rates* in 1933-7 were 14.4, 14.8, 14.7, 14.8, and 14.9. It may well be that the actual birth rate in 1933 was not lower than in 1935. And which year had the highest birth rate is anybody's guess.

In periods in which rationing of food induces parents to hasten birth registration or de-rationing of food removes this incentive the official birth figures, of course, are absolutely misleading. From 1918 to 1919 the number of registered births (which alone appeared in the official statistics) increased from 662,661 to 692,438 or by only 29,777. Actually, the number of births registered in 1918 was much

* For explanation of how these and other values are calculated, see *Glossary*.

larger than the number of births that occurred in that year while the reverse was true in 1919, and the increase in the number that occurred has been estimated at three times the increase in the number of births that were registered. In 1938-40, the numbers of births registered were 621,204, 619,352, and 607,029 respectively. How many births actually occurred in 1938 it is impossible to tell. In 1939 and 1940 – according to the *Statistical Review for* 1940 (published in 1944) – the numbers were 614,479 and 590,120. It is most welcome that the Registrar-General, who naturally is more interested in birth registration than in birth statistics, has at last yielded to the demographers' urgent demand for dealing with births according to the date of the event, and has published the numbers of male and female legitimate and illegitimate live and still births which occurred in 1939 and 1940. But the statistics for those years, showing order of birth and duration of marriage, unfortunately still refer to registered births and, therefore, do not convey a true picture of the decline in fertility during the first period of the war. These statistics include for 1939 54,144 live births which occurred in 1938 but were registered only in 1939, while they exclude 49,271 which occurred in 1939 and were registered in 1940. The statistics for 1940 include those 49,271 births, but exclude 32,362 which occurred in 1940 and were registered in 1941.

The deaths up to now have likewise been shown by date of registration. But here the consequences are less serious. According to a statement published each year in the Registrar-General's *Statistical Review* 'the time lag between occurrence and registration is usually only a day or two.' It would seem, however, that the exceptions to this rule are very numerous. Of the twenty-three tables on mortality embodied in the *Statistical Review* one shows the deaths by months of occurrence. A comparison with the returns by date of registration reveals that the differences are sometimes pretty large. From the third to the fourth quarter of 1935, the number of registered deaths increased by 22,677,

or 22.7 per cent, while the number of actual deaths increased by 24,785, or 25.1 per cent. It seems desirable, therefore, that henceforth not only the births but also the deaths be classified throughout by date of occurrence.

The Population (Statistics) Act introduced only some questions of minor importance to be asked on the registration of death. But the collection of details about deaths has been fairly ample for many years, and the mortality statistics of England compare favourably with those of other countries. I would even go so far as to plead for the curtailment of the published tables in one respect. I would advocate that the publication of standardized death rates be stopped. The standardized death rate, which is meant to convey a better picture of the trend of mortality than the crude death rate, has decreased from 20 in 1876-80 to 9 in 1935-9. The crude death rate has decreased only from 21 to 12. This crude rate is no adequate gauge of the trend of mortality, as it is calculated without regard to the changes in the age composition of the population. Since the age composition is now more favourable than sixty years ago, the crude death rate overstates the decline of mortality. The official standardized death rates are those which would have been recorded if the age composition of the population had been the same as in 1901. All depends, of course, on what year is taken as a standard, and it so happens that by choosing the year 1901 the decline of mortality in the last sixty years is overstated still more than by a comparison of the crude death rates. To compute what the death rates would have been sixty years ago and what they would be now if the composition of the population by age at both dates had been that of 1901 is perfectly futile. It is just as futile as to compute what would have been the death rates then and to-day if, both in the late seventies and now, the composition of the population by occupation had been the same as in 1901. But the computation of such standardized death rates is not only futile, it is a nuisance. Nothing, I am convinced, has contributed so much to conceal the actual trend of mortality in England as the

regular publication of these standardized death rates. The correct death rate derived from the life tables has decreased in the last sixty years from 23 to 16 or only by about 30 per cent. England, which in the 1880's had a lower mortality than, for example, Germany, Holland, and Switzerland, had in the 1930's a higher mortality than those countries. The time that is wasted in computing misleading standardized death rates could not be better used than in studying why the progress achieved in lowering mortality in England lags behind what has been accomplished in a good many other countries.

The position is particularly unsatisfactory as regards life tables. Thirty years ago such tables were available for 1838-54, 1871-80, 1881-90, 1891-1900, 1901-10, and 1910-12. Since then tables have been published only for 1920-2 and 1930-2. While the earlier tables comprised all years from 1871 to 1912, the recent ones cover only six of the thirty-two years elapsed since 1912. Formerly the bad years were taken with the good years. It is obvious that the results of the new procedure, which completely ignores not only the war years but also such a bad peace year as 1929, are much less conclusive. The existing life tables should be supplemented without delay by a life table for females for 1911-20, and by tables for each sex for 1921-30 and 1931-9. The necessary data are all available in the Registrar-General's Office, and by using modern short-cut methods which yield results sufficiently accurate for all practical and scientific purposes a life table can be computed in a few hours.

The marriage statistics in England are not as ample as the death statistics but they are not as meagre as the birth statistics were until 1938. As in the case of the death statistics it is not so much the tables showing the basic figures which need modification but rather the published rates and averages. The Registrar-General's *Statistical Review* gives the marriage rates of (*a*) bachelors and divorced men, (*b*) widowers, (*c*) spinsters and divorced women, and (*d*) widows. This lumping together of single and divorced persons was immaterial sixty or seventy years ago when the

marrying divorced persons numbered only 100 a year and constituted only 0.2 per cent of the remarrying persons, but it is most confusing to-day, since in 1939 no fewer than 10,698 or 20 per cent of the remarrying persons had been divorced. One average which is particularly misleading and which is published every year in the *Statistical Review*, is the average age at marriage. This figure was rising before the war and gave the impression that people nowadays marry[13] later than in former times. But it was rising only because the population was ageing. It is obvious that in countries where owing, for example, to a heavy decrease in fertility the proportion of younger spinsters decreases, the average age at marriage may increase, even if the nuptiality of the younger spinsters rises while that of the older spinsters declines. Since 1931 the frequency of marriages in England has increased enormously. Yet the average age at marriage of spinsters rose in every year up to 1937. No wonder that people who see those figures conclude that the increase in the number of marriages was largely due to the contraction of marriages that had been postponed during the depression. But a correct computation of the mean age at marriage of spinsters, that is of the mean expectation of single life at birth for those who eventually marry, shows that it has actually decreased in every year since 1931. The additional marriages concluded in that period were then early marriages, not delayed marriages.

The correct mean age at marriage can be derived only from a nuptiality table which is constructed according to the same principles as a life table, and which shows the probability of marrying. Many official nuptiality tables have been computed in the course of the last forty years in foreign countries, but none in England. Our knowledge of the frequency of marriages, in so far as it is based on official documents, is, therefore, quite defective. As in the case of life tables all necessary data are available in the Registrar-General's Office, and nothing could destroy as quickly the myth that our population problem may be

solved by an increase in marriages as the publication of official nuptiality tables.

5. *Official statistics and population problems.*

In February, 1944, the Government set up a Royal Commission on Population. Its first term of reference is 'to examine the facts relating to the present population trends in Great Britain.' Let us assume that, on being appointed, a member of the Commission would have tried to examine the facts by consulting all published official statistics. He would have found that the most recent general census available was the one of 1931 and that the covering report was not yet prepared; that no fertility inquiry had been made since 1911; that all birth statistics were based on the date of registration and were therefore somewhat uncertain; that the most recent statistics of the father's occupation were those of 1921; that no data collected under the Population (Statistics) Act of 1938 had been published so far. If he had looked for gross and net reproduction rates or for nuptiality tables, he would have seen that such rates or tables have never been published and never even been mentioned. If he had asked for any official publication on population trends he would have been given the Registrar General's White Paper *Current Trend of Population in Great Britain*, of which Earl De La Warr said in the House of Lords on June 8th, 1943: 'This Report, if I may say so, is completely misleading and therefore extremely dangerous. I cannot see the reason or excuse for a Report of this character unless it is just an attempt to allay public concern on a problem that is in fact dangerous to the extent that the public do not recognize it.' If he had pointed out that the Government in that same discussion had announced that the Minister of Health 'proposes to publish a document on the lines of the recent White Paper, in which the statistical outlook would be set out and discussed in a reasoned and balanced manner,' he would have been told that the plan to publish such a document had been abandoned.

Since the appointment of the Royal Commission the position has improved considerably.

1. The results of the emergency census taken for purposes of national registration on September 29th, 1939, were published in the spring of 1944. The report shows the civilian population by sex, age, and marital condition. The returns are less trustworthy than those obtained at the general censuses, and the data for men are particularly defective inasmuch as they exclude (for England and Wales) about 900,000 non-civilians; but our knowledge of the age composition and the marital conditions of females has become much more up to date.

2. The Government published in the summer of 1944 data for 1940 collected under the Population (Statistics) Act; similar figures for 1939 were published in the autumn of 1944, and shortly thereafter for the second half of 1938.[13] The tables for 1938 are accompanied by a covering report which shows the gross and net reproduction rates for 1938. Unfortunately the text is written in the same vein as the White Paper on current trends of population. The Registrar-General evidently thought that the main object of such a report was to fight what his Medical Statistical Officer called "that lamentable sense of national inferiority from which a *large section of the population now seems to be suffering.'*[14] The essence of his argument is that the population problem is not serious since a population decline could be prevented by encouraging marriage and particularly early marriage. For 1939 and 1940 only tables have been published, but no rates and no text. It is to be feared, therefore, that in their present state these statistics will be of little use to the members of the Royal Commission. However, the basic data are now available, and it should not cause insurmountable difficulties to relate them to other data hidden in the Registrar-General's Office and to provide an unbiased interpretation of the figures.

3. The Registrar-General, in the spring of 1944, published for 1934-43 'approximate reproduction rates, corresponding

to the births which occurred in each year and making allowance for a continuing improvement in survivorship conditions.'[15] In his *Statistical Review* for 1938 he had included a net reproduction rate computed according to the principles accepted all over the world (and adopted by the League of Nations and the International Statistical Institute), which imply that such rates should be computed on the basis of current fertility and mortality. His new rates take no account whatever of current mortality. Although in 1940 fertility was lower and mortality was much higher than in 1935, he obtains for 1940 a higher reproduction rate than for 1935 because, irrespective of the facts, he assumes year-in year-out a steady gradual 'improvement in survivorship conditions.' These rates are not comparable with those of any other country; they are speculative because all estimates of future survivorship conditions are uncertain; they tend to overstate reproduction because they disregard fluctuations in mortality. But if they were recomputed on the basis of current mortality they would be most useful.

A start, no doubt, has been made in the course of the last few years to increase our knowledge of the demographic position of England. But much has still to be done in order to enable the Royal Commission 'to examine the facts relating to the present population trends.' A few things have been suggested before, such as the computation of life tables and nuptiality tables, of gross reproduction rates and of genuine net reproduction rates, and a proper analysis of the statistics collected under the Population (Statistics) Act up to 1944. But the most important task of all is the immediate taking of a special fertility (or family) census which would fill many gaps caused by the numerous sins of omission committed in the course of the last decades. Such a fertility census would convey a comprehensive picture of essential demographic facts upon which (to use Farr's words of 1844) 'the greatest ignorance prevails,' for example, the incidence of childlessness, the spacing of births, fertility differences between occupational and social groups,

and the distribution of families of various sizes. The information to be derived from such a census is indispensable for a serious study of the population problem and for the framing of an adequate population policy.

6. *Future of Administration and Science.*

It may well be that in some very small countries population and vital statistics do not suffer if they are prepared in a Registrar-General's Office, but this combination is to be found in no large country except England, and it has yielded here quite unsatisfactory results. It seems, therefore, advisable to create an independent office dealing with population and vital statistics. Whether such an office should also be put in charge of some other related statistics is not of decisive importance. *The Economist* of October 7th, 1944, contained the following suggestion:

> It is already contemplated to take the census of production each year after the war; formerly it was taken every five years. There is a strong case for taking a census of distribution at frequent intervals, perhaps every two years. Similarly, the interval between population censuses has been far too long in the past; it might well be reduced from ten to five years. But if the number of such statistical investigations is to be increased and if they are to be carried out at short intervals, the existing facilities at the disposal of the Government will have to be overhauled. It might be an advantage, for example, to follow American practice by creating an organisation analogous to the Bureau of the Census, that is by making a single organisation responsible for all censuses. The creation of a strong permanent organisation would not merely simplify the procedure, but it should make for speed in the assembly and publication of statistics.

The American Bureau of Census is in fact in charge not only of population censuses but also of vital statistics, and an organization analogous to this Bureau may prove as beneficial here as it has proved in the United States. The only reasonable objection which may be raised against the proposed change is that it would *not necessarily* 'make for speed in the assembly and publication of statistics.' But it is an incontrovertible fact that for several decades publication of population statistics in this country has been slower

than in any British Dominion or Colony or in any foreign country. An outstanding example of speed in publication is to be found in India. The area covered by the Indian census of 1931 was thirty times as large as that of England and Wales, and the population was nine times as large. Yet, the forty-nine volumes of that Indian census which included an admirable text of several hundred thousand words were published within thirty months after census date. Would anyone suggest that it is easier to take a census in India, that it is easier there to instruct the supervisors and the enumerators (2,000,000 as compared with 40,000 in England), to assemble the filled-up forms at headquarters, or to train the necessary clerical staff for coding, punching, and attending the electric tabulating machines? And would anyone suggest that with the present organization it would be possible here to achieve what has been achieved in India?

Difficulties, it is true, may arise in finding the adequate personnel for the new organization. The leading men should be competent, unbiased, eager, and preferably young. It is here that Science can play an important part. Our universities should establish chairs for demography, and the students of demography should be thoroughly trained in statistics. This training would enable them to find a position as statisticians if they fail to secure employment as demographers. But the demand for demographers will be considerable in the future. The increasing importance of the population problem will afford many opportunities of doing useful work in this country, and the great development schemes in the Colonies cannot be carried out effectively without the assistance of expert demographers.

In the field of demography, as in many other fields, the Administration needs the co-operation of Science. But there is hardly any other field in which Science needs so much the co-operation of the Administration. The demographic scholar can discover methods by which the basic demographic data may be correctly interpreted but he himself cannot collect those data. They can be collected only by

the Administration, and his chances of getting the data he needs will obviously be much greater if he contributes towards the education of the future personnel of the Administration.

NOTES

1. *Natural and Political Observations*, p. 72. London, 1662.
2. See *ibid.*, p. 12.
3. Thomas Sprat, *The History of the Royal Society of London, for the Improving of Natural Knowledge*, 3rd ed., p. 67, London, 1722.
4. See *The Economic Writings of Sir William Petty*, ed. by Charles Henry Hull. 2 vols. Cambridge, 1899.
5. 'An Estimate of the Degrees of the Mortality of Mankind, drawn from curious Tables of the Births and Funerals at the City of Breslaw,' *Philosophical Transactions*, vol. 17, No. 196, Jan. 1693, pp. 596-610; 'Some further Considerations on the Breslaw Bills of Mortality,' *ibid.*, No. 198, March 1693, pp. 654-6.
6. *40th Annual Report of the Registrar-General of Births, Deaths, and Marriages in England* (1877), p. xl.
7. *6th Report* (1842), p. xxvii.
8. *30th Report* (1867), p. 222. See also *14th Report* (1851), p. xiii; *16th Report* (1853), p. x; *27th Report* (1864), pp. xix-xx; *Supplement to 35th Report* (1872), p. xi.
9. See, for example, *Congrès International de Statistique à la Haye, Compte-rendu des travaux de la septième session, seconde partie*, p. 533. The Hague, 1870.
10. *Census of England and Wales*, 1921, *General Report with Appendices*, p. 78. London, 1927.
11. *Ibid.*, p. 84.
12. See R. R. Kuczynski, *The Measurement of Population Growth*, pp. 83-90. London, 1935.
13. See *Statistical Review for the Year* 1938, *Tables, Part II, Civil;* same for 1939 and for 1940. London, 1944.
14. *British Medical Journal*, March 21st, 1942.
15. See *Births, Deaths and Marriages registered in the Quarter ended 31st December*, 1943, p. 1.

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What the Earth is made of

ERNEST TILLOTSON

Introduction.

THE earth is nearly a sphere having an equatorial diameter of 12,756·776 kilometres (7,927·06 miles) and a polar diameter of 12,713·7 kilometres (7,900·29 miles). It has a mass of $5 \cdot 98 \times 10^{24}$ kilograms (5,870 million million million tons) and it thus weighs 5·5168 times as much as it would if it were made solely of water. The corresponding ratio for average surface rocks is 2·6, and thus we see that the interior of the earth must be made of material much more dense ('heavy' when we take unit volume). Our knowledge of the interior of the earth is obtained by inferences from observations and experiments made within the uppermost 4 or 5 kilometres (3 miles) of thickness or depth. In our task of finding what the earth is made of we therefore proceed by making a mental model of the earth, the parts of the model being constructed from our observations and deductions from experiments. We can then amend this model if necessary as new facts come to light. That we do alter it from time to time and that we are still prepared to do so, and to discuss alternatives, indicates that our present model is not perfect. Its lack of perfection is caused by our observations being incomplete, and some of our deductions faulty. Let us examine the 1948 earth model, and the observations and deductions used in the making of it.

A glance at a cliff-face shows the rock to be arranged in layers and these layers to be concentric with the earth's centre. It is not, therefore, a wild flight of fancy to imagine the earth to be made up of concentric spherical shells, something like an onion, these shells increasing in density as we go towards the centre (see plate 20). The next obvious

step is to try to discover how thick these shells are individually, and of what kind of material they are likely to be made. Let us first look at the outer 4 or 5 kilometres thickness.

What the geologist has to say.

When the soil and sub-soil have been cleared away from part of the earth's surface by wind, streams, glaciers or other natural agencies, or by the hand of man as in quarries and mines, we can see the rocks. Rocks may be classified into three types, sedimentary, igneous and metamorphic. Sedimentary rocks are those which have been deposited by the agency of wind or water; igneous rocks have been formed by volcanic action, that is they have been molten, and metamorphic rocks are either of the above altered by heat or pressure or both. Sedimentary rocks may be recognised by examining the individual mineral grains of which the rock is composed, when these are seen to be water- or wind-worn, and by the presence in sedimentary rocks of the remains of the fishes, animals or plants which were living at the time when the rocks were deposited and which are now found as fossils. By examining these fossil remains and by noting carefully the relative positions of undisturbed horizontal beds as they occur one above the other we can distinguish a sequence, which, in the British Isles has been worked out, and the groups of rocks given names as follows: at the base of the sequence and therefore the oldest sedimentary rocks, pre-Cambrian, and above this in order as the rocks were deposited more and more recently, Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Eocene and Oligocene, Pliocene and Recent. Igneous rocks may be recognised in that the individual mineral grains have not been rounded, the rocks in mass are not arranged in layers or strata, but they have been intruded into the surrounding sedimentary rocks and they do not contain fossils. The character of metamorphic rocks is indicated by their position amongst other rocks, i.e., near intensely contorted strata or igneous in-

trusions, and by their appearance in hand specimens or in thin slices under the microscope. If at one time they were sedimentary and contained fossils these will have been altered beyond recognition. The examination of the individual mineral grains singly or in thin sections under a microscope assists identification.

The various minerals needed for our civilisation are found concentrated in ore bodies, which makes commercial exploitation possible. The presence of these minerals in the crust as a whole is often in very small proportions. For example iron is present to the extent of about 5 per cent by weight of the whole crust, copper 0·01 per cent and lead 0·002 per cent. The concentration of minerals into ore bodies is often by volcanic action, but occasionally by water sorting or other natural process.

The thicknesses of the individual strata vary greatly from one to another, and even the same stratum is of different thickness from place to place. Sometimes one or more strata may be entirely absent, causing a non-sequence or unconformity at that point. At the thickest places as in the Alps, Andes, Himalayas and Rocky Mountains the total thickness of sedimentary rocks may be 4 kilometres ($2\frac{1}{2}$ miles) whilst under the Pacific Ocean it is supposed that they are entirely absent.

What the geophysical prospector tells us.

When a geologist examines the stratified rocks at the earth's surface and finds them dipping or their bedding planes sloping into the ground he can take the angle of dip and with a knowledge of the topography draw a section to show what happens to them underground. In this he is assisted by other observations of other strata in the district, and possibly by the reappearance of the original strata (recognised by fossil assemblage) further away. This is called extrapolating from known data to unknown regions. The only real proof that his extrapolations are justified is by drilling and examining the cores so obtained. This is very

expensive and nowadays there are cheaper ways of testing geological inferences obtained in the above manner. These less expensive methods are called geophysical prospecting, because we make use of the physical properties of the rocks and examine them with the apparatus which physicists normally use in their laboratories and observatories. The four chief methods are magnetic, electrical, gravitational and seismic. We will examine these methods in some detail, particularly the seismic method, as they are also useful for the larger work of probing the deep interior of the earth.

The magnetic method depends upon the magnetic susceptibilities of various minerals in the rocks. The presence of deposits of iron, nickel or cobalt ore can readily be detected by this method even if they are buried to a depth of over 1,500 metres (5,000 feet). Ores which occur in association with, say, magnetite or pyrrhotite can also easily be located by this means, though the percentage of iron present in a mineral is not the only criterion of its magnetic susceptibility. Occasionally certain igneous rocks such as basalt, diabase, diorite or serpentine are more strongly magnetic than, say, haematite, which contains a higher percentage of iron. In magnetic surveys the vertical component of the earth's magnetic field at a given point is usually found, as this in practice is more sensitive for the purpose of locating underground deposits or determining tectonic structures than finding the horizontal component. In most instruments of the type used in the field this vertical magnetic force is compared with an opposing force in the instrument due to, say, gravity, torsional or bifilar suspension or the magnetic force of an auxiliary magnet. The magnetic survey is the quickest and cheapest of all surveys. It does not need a trained observer and is independent of topography. Its limitations are due to the fact that only some rocks have magnetic properties. It has proved extremely useful in such countries as Sweden.

The gravitational method of obtaining evidence concerning underground structures depends on the variations of

density of the rocks as we go from place to place. The work is not carried out by means of a pendulum which would measure the absolute value of gravity in any place, but usually by means of a torsion balance which measures horizontal *variations* in gravity. The first effective torsion balance was constructed by Baron Roland von Eötvös, Professor of Physics at the University of Budapest, in 1888. One type of the Eötvös torsion balance consisted of a light horizontal beam with equal masses of platinum at each end – one actually at one end of the beam and the other suspended at a depth of about a metre from the other end of the beam. The system was suspended from the mid-point of the beam by means of a delicate suspension wire, the torsion in which acted in opposition to the tendency of the earth to rotate the beam into one definite position. The suspended beam carried a mirror by means of which, in association with a scale mounted on a separate stand, a telescope could be used to observe changes in the position of equilibrium of the beam. The greatest success of the instrument lies in delineating the extent of large bodies of very high or very low density when these occur fairly near the surface. The boundaries of salt domes, associated in some parts of the world with petroleum deposits, can be mapped efficiently, after the necessary corrections for the effects of surface features have been applied.

Electrical methods have been used to determine the depths and dips of hidden layers of rock and are based on the differences in electrical conductivity between adjacent rock bodies. These differences may be very large and hence there is a greater range in this method than in any of the other methods. The oxidation of certain sulphide ores produces natural earth currents, but in other cases it is necessary to set artificial electric currents in the earth and ascertain their effects.

The seismic method of prospecting is probably the one which is capable of the greatest accuracy to-day and the one which has the greatest possibilities of advancement in

the future. The cost is fairly high but it pays dividends by its efficiency and it is much cheaper than drilling. Relatively simple geological structures such as salt domes, anticlines, and horizontal strata have been dealt with successfully up to the present time. The earthquake waves are produced artificially at a known instant by firing electrically a quantity of explosive. In the neighbourhood of the Gulf of Mexico, when prospecting for salt domes, 70 to 90 kilograms (150 to 200 lb.) of T.N.T. are buried 4 to 6 metres (14–20 feet) underground and fired electrically. In that part of the world the hole is sometimes left unfilled. In England and more populated areas less explosive is employed, though the people of Leyland in Lancashire thought they had experienced a natural earthquake when a shot was fired in a 30 metre (100 feet) borehole in the neighbourhood when prospecting for oil on Sunday morning, 21 July, 1946. The action of the explosive is to generate at least two types of waves. In the first type, called primary (P), the particles move backwards and forwards in the direction of the wave, which is thus longitudinal. It is of the same nature as a sound wave though often the frequency of the wave is such that human beings cannot hear it, and an instrument is required for its detection and reception. The second type of wave is called secondary (S), and as the wave passes any point the particles in its path move to and fro at right angles to the path. It is thus a transverse wave, and is slower than the P wave. Moreover it must be transmitted through solids. Liquids and gases cannot transmit S waves. In seismic prospecting at present P waves only are used, though in future S waves may be employed. The instruments used to detect these waves, which are similar to two waves present in natural earthquakes, are called seismographs and the records obtained by them seismograms. In principle, the horizontal seismograph consists of a weight fixed at one end of a nearly horizontal rod, which is pivoted at the other end. When the earth quakes everything moves except the weight, which stands relatively still. The relative movement

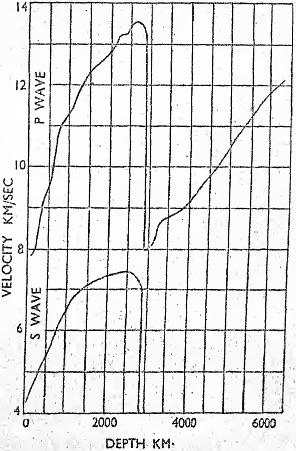


Fig. 12.—The speed of travel of both S and P waves increases as we go deeper into the Earth, until the core is reached.

of the weight and the surroundings, a few thousandths of an inch, is magnified and then recorded on paper fixed to a revolving drum. Time marks are also put on the paper.

There are various ways of arranging the work in seismic prospecting, but here we will consider only two ways – refraction shooting and reflection shooting. Suppose in the first instance that the area has been geologically surveyed and that a salt dome is to be expected. We first wish to find the horizontal extent of the salt which is surrounded by Tertiary strata. If we fire a charge of explosive at S (Fig. 13) and have seismographs at A, B and C, equal

distances from S, to receive the P waves, and if the ground were homogeneous (uniform throughout) the waves would all be received at the same time on the three seismographs.

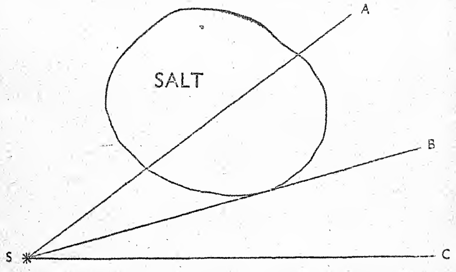


Fig. 13.—A plan view of seismic prospecting.

But as SA travels through the salt, which transmits P waves twice as fast as the surrounding rock, the waves will arrive at A before they arrive at C. By using a large number of seismographs it is relatively easy to distinguish the tangential ray SB and hence to find the limit of the dome in this direction. The prospector may then work round the deposit in a similar manner.

The next problem is to find the thickness of the overburden – the depth of the top of the salt. If an explosion at S (Fig. 14) causes an artificial earthquake to have S as its focus, P waves will travel outwards in all directions from S. Those vertically downwards will continue uninterrupted; those making a small angle with the normal to the surface will travel to the top of the salt and there be bent or refracted in a similar manner to that of a light wave going from air to water. A ray SP striking the top of the salt at the critical angle A in fig. 14

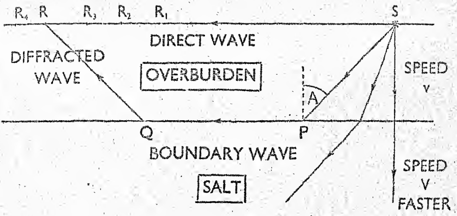


Fig. 14.—A section through the Earth's surface.

(such that $\sin A = \frac{v}{V}$)

will not go deep into the salt but will travel along the boundary with a speed equal to that in the salt (V). v is the speed of the P wave in the overburden. From every point along the boundary diffracted waves will come up through the overburden to the surface and these will be received by seismographs placed at R_1, R_2, R_3, R and R_4. The direct wave, with its whole course through the overburden, will also be received by these seismographs. On each seismogram the times of arrival of the direct wave and diffracted wave are noted and the point R found where the two waves arrive simultaneously. If the distance $SR=2x$ and if the path SPQR is such that for SP,

$$\sin A = \frac{v}{V}$$

then it may be proved that the depth of overburden y is given by

$$y = x\sqrt{\frac{V-v}{V+v}}$$

Now v and V can be found from the slopes of the distance-time graphs for the direct and diffracted waves.

It would be impossible to use the above method if the speed of the P wave in the lower layer of rock were slower than the speed of the P wave in the upper layer.

Reflection shooting is more difficult. It depends upon PQ (Fig. 14) being a good reflecting horizon, and the shot in the borehole being sufficiently powerful for echoes to be transmitted through the overburden so that they can be recognised as such at R_1, R_2, R_3, etc. This must be so in spite of the much larger direct waves arriving at the seismographs, and moreover the timing of the echo must be carried out with an accuracy of a thousandth of a second. Only really good modern apparatus will accomplish all this. If the earth is multi-layered at that point, the prospector must find which horizon is giving the echoes but otherwise the field problem is merely one of finding the speed of the P waves in the upper layer and applying this to the timing of the echo. For this work a seismometer with short natural period and low sensitivity is fitted with an electromechanical trans-ducer, usually of the moving coil type. The P wave is thus mechanically received and the movement converted into electrical impulses. These are then magnified several million times by means of an electronic amplifier which is also a band filter, letting through only frequencies of 30 to 60 per second. The amplifier is also controlled so that it only starts its work after the direct waves have passed and when the echoes are due to arrive. The electrical impulses are then passed through a small d'Arsonval type galvanometer and recorded photographically on a strip of paper moving 2 or 3 feet per second. Time marks are placed on the same strip by means of a mirror reflecting a spot of light from an oscillograph oscillating at 100 cycles. Clear marks are thus placed on the strip each five-thousandth of a second. A seismic survey verified and measured the shale-capped carboniferous anticline at Eakring in Nottinghamshire, England, where oil was later found by drilling.

Thus far we have considered the exploration of the outer

layer of the earth, which is the one handled by geologists. This portion of the earth is called by geophysicists the sedimentary layer. It is largely sedimentary in the geological sense as it is composed chiefly of such rocks as limestone, sandstone, shale and clay, which are the products of weathering and reconstitution of the original stony surface material. We will now probe deeper.

The interior

The basement complex of pre-Cambrian rocks, about 1,500,000,000 years old, is visible in Finland and consists there of 52.5 per cent by weight of granite, 21.8 per cent mixtures of granite, sediments (the earliest deposited on Earth) and old Volcanic rocks, 4.0 per cent granulites, 9.1 per cent schists (a metamorphic rock whose crystals are distinguishable to the naked eye, which is conspicuously thinly foliated and in which felspar is absent), 4.3 per cent sandstones and quartzites, 0.1 per cent limestones and dolomites and 8.2 per cent basic rocks unlike granite but once molten. It will be seen that it is truly granitic in composition, originally largely igneous though partly sedimentary, but now largely metamorphic in texture. There may be local variations in this metamorphosed mass of pre-Cambrian rocks, but according to seismological evidence it is fairly uniform in character and about 10 kilometres ($6\frac{1}{4}$ miles) thick. It is called the granitic layer and envelops the whole earth with the exception of the Pacific Ocean.

Under the granitic layer is another uniform layer some 20 kilometres (nearly $12\frac{1}{2}$ miles) thick which has a composition intermediate between granite and basalt and which, in consequence, is called the intermediate layer. This may also be absent from the bed of the Pacific Ocean, but it is present everywhere else in the Earth.

The sedimentary, granitic and intermediate layers together form the Crust of the earth which took its name at the time when it really was considered to be the only solid

part of the earth. Natural earthquakes and very large explosions such as the atom bomb tests in New Mexico on 16 July, 1945, and Bikini on 24 July, 1946, the Burton-on-Trent explosion of 27 November, 1944, the Port Chicago explosion of 17 July, 1944, and the Heligoland explosion of 18 April, 1947, all sent P and S waves right through the crust and thus give us data concerning its constitution, structure and size.

Below the crust is the mantle, which continues to the edge of the core. The top of the mantle is probably the floor of the Pacific Ocean and it appears likely that large local reservoirs in the mantle, caused by a temporary relief of pressure, were the sources of the great basaltic lava flows of the Deccan of India and the Giant's Causeway in Northern Ireland. The mantle is thought to consist wholly of basalt (dark coloured, dense, basic, alkali rock poor in silica) crystalline for the top 70 kilometres (43½ miles) and glassy below. Towards the base of the mantle metallic ores are probably present in greater proportions. Elsewhere various small changes in composition or texture have been suggested from time to time, but these changes are not sufficiently obvious to have gained universal acceptance. The mantle is solid throughout and transmits S waves. It has a rigidity of 16×10^{11} dynes per square centimetre (10,352 tons wt. per sq. inch) which is about twice as rigid as steel.

The base of the mantle is at a depth of 2,780 kilometres (1,728 miles) from whence there is a gradual change to 3,000 kilometres (1,864 miles) where the core begins. The core ranges in density from 10·1 gm. per c.c. (630·5 lb. per cu. ft.) at the outside to 12·2 gm. per c.c. (761·6 lb. per cu. ft.) at the centre. It is thought to be liquid and may be composed of iron and nickel. It focuses earthquake waves which pass through it (as a magnifying glass focuses light) to a point in the antipodes and around this focal area is a shadow zone stretching roughly from 102° to 143° from the epicentre (point on the earth's surface directly above the

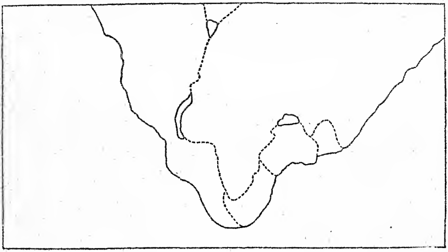
starting point of an earthquake). Furthermore, echoes of waves from natural earthquakes reflected from the core boundary can be distinguished on seismograms and these, as in reflection shooting (seismic prospecting) enable us to find the depth of the boundary. The high pressures existing and the physical properties of the material at these high pressures keep the core stable, though at these temperatures and pressures it may constitute a transition region where physical and chemical properties begin to change strongly. (These conditions are nothing like the conditions inside stars, however.)

Temperatures within the earth.

The temperature gradient in the crust of the earth is such that it gets about 1°C warmer in every 30 metres (1°F for every 18 yards deeper approximately) though there are large variations such as over salt domes and granite plugs, and over basement rocks. The heat current through the earth's surface is about 10^{-6} calories per second per square centimetre ($3{\cdot}69 \times 10^{-6}$ British Thermal Units per second per square foot) and this appears to be largely accounted for by the estimated spontaneous production of heat by the known average radioactive mineral content of rocks in the uppermost 40 or 50 kilometres (25 to $31\frac{1}{4}$ miles) of the earth. Furthermore, laboratory experiments tend to confirm that at high pressures rocks and minerals and metals are superconducting to heat and we are thus led to the conclusion that the interior of the earth no longer contributes to the heat flow through the surface. Except for the outermost part of the mantle the temperature in the interior of the earth appears to be not far from the temperatures existing at the time when the crust solidified.

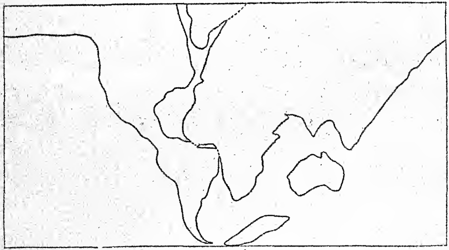
When the earth was originally gaseous it is thought to have had a temperature of 6,000° absolute (5,727°C = 10,340°F); the crust became solid after about 15,000 years and soon afterwards the surface cooled sufficiently for oceans to condense. The temperature of the earth's centre

may now be just over 2,000°C (3,632°F), the temperature at about 80 kilometres (49¾ miles) being about 1,200°C (2,192°F).



(*a*)

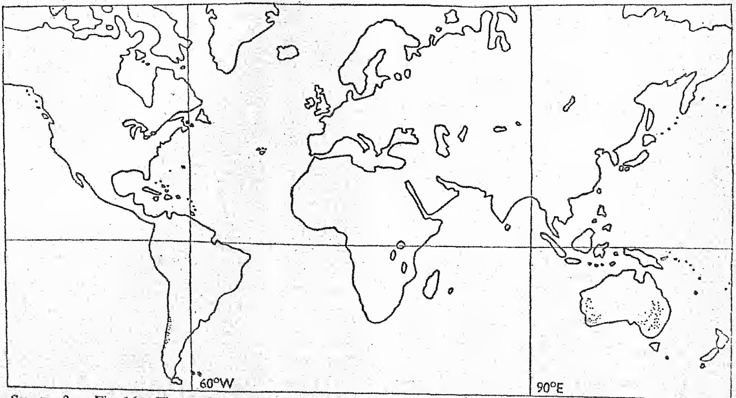
STAGE 1.



(*b*)

STAGE 2.

Fig. 15.—The Wegener theory of Continental drift supposes that at one time all the continents of the world were bound in one great land mass (see (*a*)). Under the influence of the Earth's rotation they began to tear apart, attaining an intermediate stage (*b*).



STAGE 3. Fig. 16.—The world to-day: the continents are separated. But signs of the old state of affairs remain in the structure of the continents, and in the distribution of certain animals and plants.

Forces in the earth's crust.

A consideration of the conditions under which the deposition of certain sedimentary rocks took place together with an examination of their fossil content, shows us that areas which are now dry land were at one time beneath the sea. It is one of the fundamental aims of geology to reconstitute past geographies and to determine, from the time when the oceans first formed on the earth, the changing positions of the shore lines. During the course of this time, points on the earth's surface have changed their relative vertical positions through several thousands of feet, and rocks which were deposited horizontally on the ocean floor have been raised to become dry land, and often compressed laterally until they have in some cases been left standing vertically, and in other cases as in the Alps and the Highlands of Scotland been turned right over. Ours is truly a mobile earth. The pressure appears to have come from different directions at different times though the whole process has been extremely gradual. For example, pressure from the North-east and/or South-west which folded the rocks of the Charnwood Forest area into axes which run North-west to South-east took place in pre-Cambrian times about one thousand million years ago. The NE – SW Caledonian axes typical of parts of Scotland were caused mostly in post-Silurian times about 400,000,000 years ago. Later on the direction changed again, for in post-Carboniferous and post-Triassic times (from 150 to 50 million years ago approximately) we find the fold axes were made to lie roughly north and south as in the Malvern Hills.

Sometimes, when the lateral pressure which causes mountains to be formed is too great for the strength of the rocks, the rocks crack or 'fault' and at the same time an earthquake takes place from the point where the first crack appears. Relative movement of the rocks on both sides of the fault also takes place. Earthquakes start or have their 'foci' at any depth in the earth down to 700 kilometres (435 miles), and earthquakes at this depth appear to have

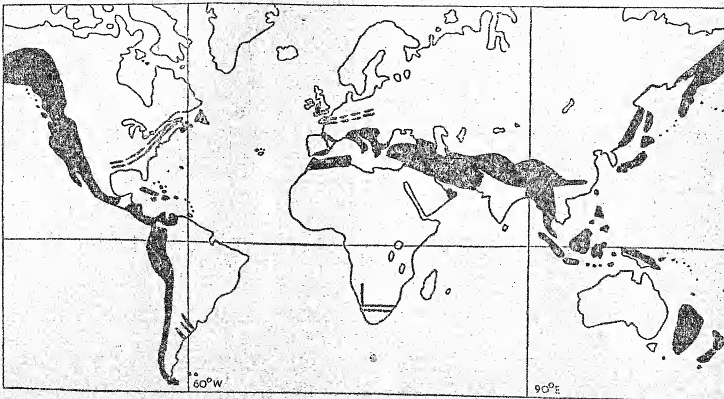


Fig. 17.—A world map of recent mountains.

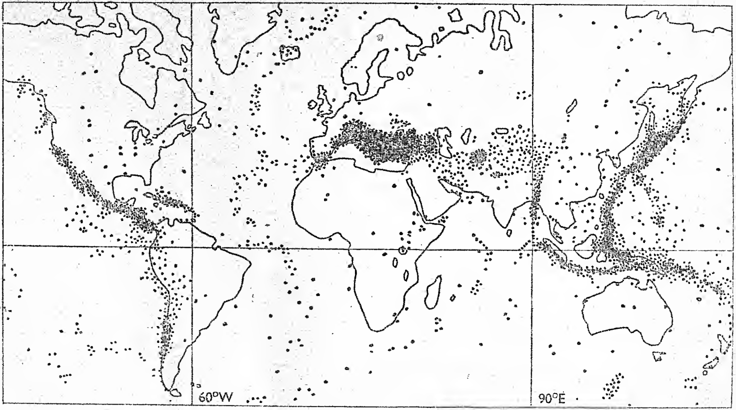


Fig. 18.—Map showing earthquake epicentres.

been caused in the same way as earthquakes which start at the earth's surface. This point is, however, still under discussion. If earthquake epicentres are plotted on a map according to their depth of origin interesting results are obtained. We find that earthquakes with shallow foci, i.e. 0 – 100 kilometres (0 to $62\frac{1}{2}$ miles) and intermediate foci, i.e., 100 to 290 kilometres ($62\frac{1}{2}$ to 181 miles) are closely associated with Tertiary or more recent mountain building (within the last 60 million years), whilst deep focus shocks, i.e. 290 to 700 kilometres (181 to 435 miles) are associated with pre-Cambrian topography (1,000,000,000 years old). What was the origin of the lateral forces in the earth's crust which from time to time have been responsible for all this movement and mountain building? Some have been due to the contraction of the earth's interior consequent on cooling, and some may have been caused by variations in temperature within the crust and upper mantle owing to radioactivity, but the full story is not yet known. Mountain building appears to have gone on at a much more rapid rate during some periods of the earth's history than at others. Let us take a look at the 'foundations' of the crust, i.e. the upper part of the mantle.

The crust of the earth is often called SIAL on account of its estimated average composition by weight, which is SiO_2 59·12 per cent, Al_2O_3 15·34 per cent, other minerals making up the remainder. The material beneath this is often called the SIMA because of a preponderance in it of minerals containing silica and magnesium. Now the upper part of the SIMA, called the astheno-sphere, yields to the crust above it. During the last (Pleistocene) ice age Scandinavia was depressed about 700 metres ($765\frac{1}{2}$ yards) by a load 3 kilometres ($1\frac{9}{10}$ miles) thick of ice, and is even to-day gradually recovering from the load. The theory of isostasy concerns this hydrostatic support of the earth's crust by the mantle and states (in one of its forms) that each vertical column of the earth's crust, in regions that have not been recently disturbed, which have a radius of at least 10 kilometres ($6\frac{1}{4}$

miles) and extend down to a definite depth of compensation (usually taken at some depth between 60 and 122 kilometres $= 37\frac{1}{4}$ and $75\frac{3}{4}$ miles) has approximately the same mass whether its column occurs in a continental, mountainous or

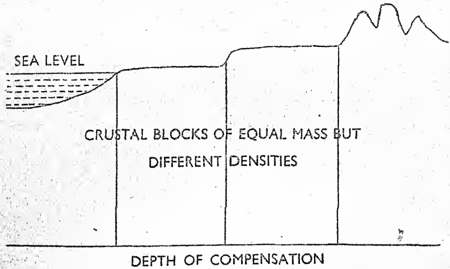


Fig. 19.—Isostasy according to Pratt.

oceanic region. The formulation by Pratt requires the density of the column to vary inversely as its height, whereas the formulation by Airy requires the density of a given layer to be constant, but under mountains the lighter surface material to extend to greater depths. Both formulations are no doubt true in different parts of the world and both rest on accurate observations of the acceleration due to gravity obtained by pendulum experiments. Regions of the earth where movement is still going on, such as the Himalayas or Alps, Rockies or Andes have not yet attained isostatic equilibrium, but older mountain chains have. On one of the latter, if we swing a pendulum at the top of a mountain it should swing more times to the minute than the same pendulum on the plain below (after correcting for distance, from earth's centre, etc.), since presumably there is a bigger mass between it and the earth's centre. We find that this is not so and the pendulums swing in the same time, thus giving evidence in support of the hypothesis.

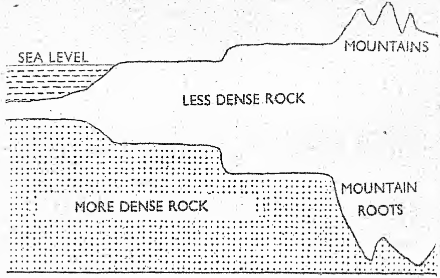


Fig. 20.—Isostasy according to Airy.

Astronomical considerations.

Our earth model must fit into its place in the solar system. Meteorites or 'shooting stars', which may be seen on most nights in England, but more particularly during November, are objects which dart across our sky apparently falling to earth, though often disappearing before they reach the earth. Evidently they are dark objects from outer space, attracted by the earth, which glow by friction with the earth's atmosphere. This white heat disintegrates them entirely if they were originally small in size, but if they were initially large enough, they reach the ground. Some which have reached the ground have been examined. They have varied in size from hundreds of yards in diameter to the size of a pea. They are of three types: Aerolites (stony), Siderolites (stone-iron), and Siderites (iron-nickel), and fall approximately in the proportion of 35 stony meteorites to 1 iron meteorite. There are very few siderolites. The iron in the siderites is octahedral in crystallisation which is the gamma or high temperature form, and in some of the siderites diamonds, a long-period high-pressure crystallised

form of carbon, are found. The aerolites are largely composed of igneous rock whose average chemical composition is very like that of terrestrial peridotitic rocks (a rock in which crystals of olivine may be readily distinguished and in which there is very little else. They are extremely poor in silica and are definitely ultra-basic). Meteorites appear to have come originally from some mass of cosmic matter which had a spherical form, increased in density towards the centre, and had cooled from a molten mass free from water before it disrupted. It is suggested that this cosmic mass was similar in constitution to the earth, with possibly the outer crust and atmosphere missing. Meteorites support the hypothesis that the mantle of the earth is composed of ultra basic rocks and that the earth's core is made of iron with the addition of some nickel.

Finally, the elastic constants of the earth's layers obtained from the rates of transmission of earthquake waves, are found to be the same as those obtained from a consideration of the tides set up in the earth by the gravitational forces of the moon and sun.

Thus we find that although the 1948 model of the earth is better than previous models, there are still large parts of our model to improve before we have a model which will work exactly like the earth itself. Observation is the key to the problems involved.

Glass

K. L. LOEWENSTEIN

THE art of glass manufacture depends on melting together a number of substances, which, on cooling rapidly, will set to give a clear, transparent solid. From a physical point of view this corresponds more to the liquid than to the solid state. For example, the change from liquid water to solid water (ice) takes place at a definite temperature, and as long as both water and ice are present the temperature of the mixture will be 0°C or 32°F; with glasses this is not so on cooling, the viscosity increases continuously, and there is no definite temperature at which the glass can be said to solidify; similarly, on heating glass from room temperature it will soften more and more without any break in the temperature curve. This is best illustrated by means of a graph,

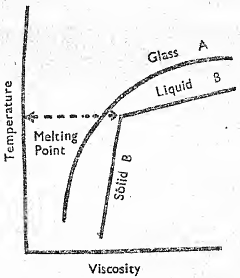


Fig. 21.

plotting viscosity against temperature. Glasses will give a curve of the continuous type (A), whereas liquids and solids give the discontinuous type (B) (Fig. 21).

For this reason the glassy state has been termed 'vitreous,' and glasses are often described as 'super-cooled liquids.' The decomposition of glass into solid constituents can take place, especially when the glass is cooled very slowly; this is called 'devitrification' This often takes place years after a glass article has been made, and there is no known method by which it can be arrested.

The properties of glass must be in accord with the functions that it has to fulfil. For example, the wires of electric light bulb filaments have to be sealed into glass. To get a good seal, not only must the coefficients of expansion of the glass and the metal be as nearly identical as possible, but also the rate of change of these coefficients must be the same at any temperature. Any serious deviation from these conditions is liable to produce fracture.

The constituents of glasses:

(1) Glass-formers. These are pure substances which can exist as glasses by themselves, and without which no stable glass can be made. For example, silica (sand) can be made into a glass, but lime, present in most glasses, or lead oxide, present in many, cannot form a glass.

By far the most important glass-former is silica; the others are germanium dioxide, beryllium fluoride, and phosphorus pentoxide; the last, in particular, has now been extensively investigated for special electrical and optical purposes.

What makes a substance a glass-former is a question of relative atomic size of the atoms making up the substance. Firstly, the cation (silicon, phosphorus, etc.), must be large enough to space around itself a number of anions (oxygen, fluorine, etc.), to permit the formation of a three-dimensional network structure; and secondly, the anion must be small enough in relation to the cation to fit into such a

structure. For example, beryllium fluoride is a glass-former; on substituting a smaller atom, e.g. lithium, for beryllium, or a larger atom, e.g. bromine, for fluorine, we find that the substitutes are too small or too big respectively to fit into the network structure.

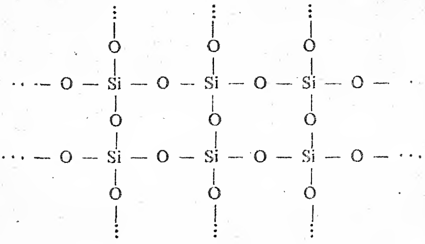
It has been found that the ratio of the atomic radii of the cation to the anion must be approximately 0·3.

The high stability of silica glasses compared with other glass-formers is ascribed to the fact that the ratio of the number of cations to anions is 1 : 2, so that each silicon atom can group around itself four oxygen atoms in the shape of a regular tetrahedron, and that each oxygen can hold two silicon atoms; furthermore, as no oxygen can hold more than two silicon atoms there is a certain flexibility in the joining together of SiO_4 tetrahedra. Hence the energy in the supercooled state is not very different from that in the crystalline state, and the tendency to devitrify is small.

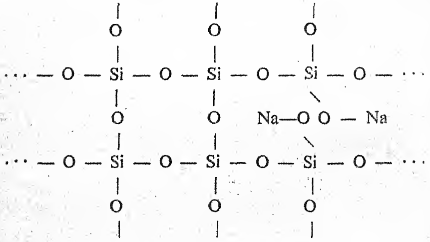
If, however, other groups besides the SiO_4 tetrahedra are incorporated in the glass structure, the tendency to devitrify is increased.

(2) Other constituents:—The breaking-up of the three-dimensional SiO_4 network by other constituents will lower the melting point of the mixture, and good glasses can be obtained at temperatures as low as 1,250°C, compared with 1,750°C for the melting point of silica.

The network can be broken up by any substance that is soluble in the glassmelt, and which has no tendency to separate out on cooling. The oxides of the alkalies (lithium, sodium, potassium, rubidium, and caesium) are the most powerful substances to break up the silica network, as each molecule of alkali oxide breaks up one – Si – O – Si – link, thus:—



Silica in the vitreous state.



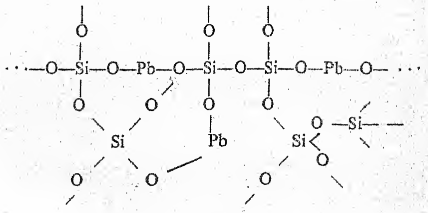
One molecule of sodium oxide, Na_2O, has entered the glass structure. (The diagrams are projections on to a plane, and do not represent relative distances, etc.)

It can be seen that there must be a limit to this process of breaking up the silica network; this limit is the formation of sodium silicate (waterglass). In glassmaking the limit is governed by the stability of the resultant glass; as a rough guide not more than 18 per cent of alkali oxide can be

incorporated into a glass without asking for trouble: the glass tends to devitrify even in the molten condition, and the finished article will be attacked rapidly by the carbon dioxide in the atmosphere.

The continuity of the silica network can also be broken up by replacing some of the oxygens by fluorine. Oxygen is divalent and can, therefore, act as link between the individual tetrahedra; fluorine is monovalent and therefore cannot. This method has its drawbacks as fluorides are not very soluble in the glassmelt, and the pots in which the glass is melted are badly corroded.

Calcium oxide (lime), barium, lead, zinc, and magnesium oxides do not break up the silica network, but thin out the tetrahedra, e.g.



The extent to which these divalent metals can be added in the form of their oxides depends on the properties of the resultant glass, the solubility of the oxide in the glass, etc. With lime, barium oxide, zinc and magnesium oxides, the glass becomes unstable when about 25 per cent is used; with lead oxide, however, glasses containing 90 per cent have been made and are quite stable. Lead crystal glasses contain 20 to 30 per cent of lead oxide.

The melting properties of most glasses can be improved by adding boric and/or aluminium oxides. These, when added in small quantities (up to 5 per cent), can form tetra-

hedra, which, being of a different size to those of silica, will distort the symmetry of the SiO_4 groups in relation to one another. This gives greater flexibility to the glass structure without breaking up the network.

The sum total of all these effects on the originally symmetrical network is that it is impossible to represent visually and accurately the structure of a glass as was attempted above All that can be said on the subject is that the average position of the individual constituents is, say, one alumina group for every 50 silica groups, on the average every 24th Si – O – Si link is broken by an alkali atom, or, for every three SiO_4 groups there is one lead atom thinning out the structure. But we must remember that these are average positions, and deviations may be considerable. It is impossible to picture the structure of glass; the lines and chains of atoms are twisted and turned in all directions; the space allotted to each atom varies, some are squeezed in, some have more 'breathing space,' but, on the average, they just about fit in. In technical language this has been termed a random network structure, common also to mixtures of liquid substances; this is another reason why the physicist calls glass a supercooled liquid.

Viscosity

DR A. E. BELL

VISCOSITY plays perhaps as large a part in the phenomena of everyday life as does friction – with which it is related. It is in fact an effect we commonly exchange for friction when the latter is undesirable. When we wish to reduce the drag between two metal surfaces, as in the moving parts of machinery, we introduce a thin layer of oil which acts as a lubricant. This replaces frictional loss of energy by a loss due to viscosity, but with a suitable lubricant the loss is much less, and the wear is eliminated. The viscosity, or resistance to flow offered by the lubricant in the bearing, remains an unavoidable nuisance, but fortunately the viscosity of a liquid in practically all cases shows a marked decrease as the temperature rises, and this means that considerably less energy is lost once an engine is warmed up. As Dr Bowden pointed out in his article on Friction the existence of such a drag between bodies is in some respects useful, in others a nuisance. It is the same here with viscosity. A reasonable amount of viscosity in a paint is an advantage since there is little flow during the time taken for the paint to harden. Too much will mean that the brush marks are retained too long and surface tension will not be able to flatten the surface before it is hard. Fortunately there are certain liquids which exhibit a reduced viscosity when they are stirred rapidly, the effect being called thixotropy. A small amount of thixotropy may be an advantage in a paint or varnish – while it accounts for some of the attractive qualities of whipped cream!

Much attention has naturally been given to the composition of lubricating oils and the properties which are desirable in them. They are all compounds of hydrogen and carbon with many carbon atoms arranged in fairly long chains.

These molecules slide over each other and one layer seems to cause a drag on the next through the entanglement of the chains. This sliding of one layer over another, like the sliding over each other of the cards in a pack, is called a shear. In Newton's great *Principia* of 1687 it was pointed out that the shearing force F is connected with the rate of shear, dv/dx, the viscosity η and the area of the layers A by the equation

$$F=\eta A \frac{dv}{dx}$$

and this is still the relation employed in measuring viscosity. Since liquids commonly adhere very strongly to the surfaces of solids the flow of a liquid through a uniform circular tube involves the sliding of concentric layers over each other with the fastest movement at the middle and a zero velocity next to the wall. This is what is called laminar or 'Newtonian' flow, and it means that the contour of the velocities across a section of the tube is of the form shown on the left.

Fig. 22.

If we think of two flat layers A and B one centimetre apart, one moving relatively faster than the other by a velocity of one centimetre per second, then clearly A will exert a forward drag on B and B will exert a backward drag on A. The force exerted per square centimetre of either layer is the viscosity of the liquid.

In a general way it is clear that viscosity results from forces existing between the molecules as they pass over each other, and it is natural that physicists should be anxious to connect the viscosity of a liquid with the known properties of its molecules. Measurements of viscosity are relatively simple and involve study of the rate of flow of liquids through fine tubes or the rate of fall of a small metal sphere

through a column of liquid. What is wanted is a science of the subject, and straight away we see that to understand viscosity we need to know a good deal about the internal conditions, one might say the constitution, of liquids. These, we know, are composed of molecules in fairly close contact and the forces between the molecules are unquestionably of electrical character. Nevertheless we can get on quite well without concerning ourselves very much about the origin of the forces and simply occupy ourselves with 'billiard ball' molecules moving about in quite a Newtonian manner. I mean that we need to think only of the momentum of moving particles and the effects of forces on them, and not concern ourselves at all with electrons and protons, still less with those wave aspects of matter with which modern physics makes us familiar.

At first sight it certainly seems as if liquids are really only very highly condensed gases or vapours. You have only to cool and compress air sufficiently and, as we all know, it begins to liquefy. Thomas Andrews[2] studied the change in the case of carbon dioxide in the sixties of last century and he produced evidence to show that there is in fact a 'continuity of state' between the liquid and gaseous conditions of that compound. His method was to study the change of volume with pressure at any given temperature, and he did in fact plot the curve for the pressure/volume relation for a series of temperatures. The shapes of these curves or isothermals are shown in the figure. Andrews found that for any temperature below 31°C there is a particular pressure at which the gas begins to liquefy: this might be called the saturated vapour pressure for this temperature. So long as both gas and liquid were present in his apparatus the pressure remained constant. So soon as the gas was all liquefied it was found that great increases in pressure produced no appreciable decrease in volume, on account of the incompressibility of the liquid. The result is that the left-hand portions of the curves are all vertical.

The continuity of the two states can best be appreciated

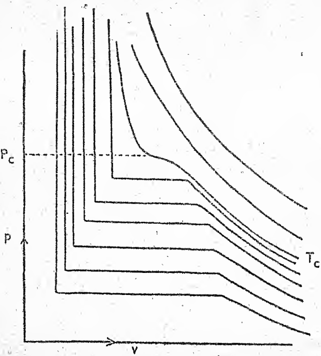


Fig. 23.—The behaviour of carbon dioxide at different temperatures (see text below for explanation); P, pressure; V, volume.

by running the eye from the bottom left-hand part of the figure up towards the top right-hand part. The curve marked T_c is the isothermal for the critical temperature, and at the pressure p_c the conditions are in fact exactly intermediate. On watching a tube half-full of liquid carbon dioxide, as this temperature is reached it is seen that the liquid surface vanishes without the liquid having boiled away. This is because the liquid and gas states have under these conditions the same density and they are as a consequence indistinguishable. If we represent the liquid at a temperature lower than T_c by the densely crowded condition of the molecules in (a) and the gas at that temperature by (b), then at T_c and p_c the two pictures have to be made identical through the expansion of the liquid on the one hand and the compression of the gas on the other.


(a)

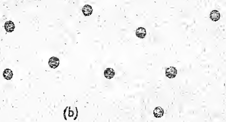

(b)

Fig. 24

In his first scientific publication the Dutch scientist Van der Waals produced (1873) an elegant explanation of the facts discovered by Andrews and others. This successfully treated the liquid state as originating from the gaseous state, and the combined work of Andrews and Van der Waals was for many years extremely influential. Jeans remarked, however, that 'there was a certain element of luck' in Van der Waal's equation having predicted the change from the gaseous to the liquid state. Today the old kinetic theory, according to which liquids closely resemble gases (in that their molecules are distributed in a purely random manner) has undergone considerable changes. The nineteenth century chemists, it must be admitted, made remarkably good progress with a theory of solution in which the molecules of the liquid were treated as if they did not exist! The dissolved substance was supposed to have its molecules distributed just as if they were the molecules of a gas and for many purposes the solvent liquid could be forgotten. There was a certain paradox in saying that this success provided support for the kinetic theory, but so it was generally supposed to be. The phenomenon of Brownian movement was probably the best visual demonstration of the general correctness of the kinetic theory. In this phenomenon, microscopic particles such as those found in Indian ink, or soil, or consisting of pollen grains or bacteria, when placed in water are to be seen under the microscope to be constantly vibrating or gyrating about fixed points so that the whole field of view is gently trembling in its appearance. Einstein gave a detailed

mathematical theory of the phenomenon, which is due to the unequal bombardments of relatively huge floating particles by the surrounding water molecules. All that Brownian movement shows therefore is the existence of molecules in a state of vibration.

It has not proved to be possible to give a mathematical account of viscosity on the basis of the old classical theory outlined in the preceding two paragraphs, and moreover there are other matters such as the existence of a more or less sharp melting point which are equally (or more) difficult. You have only to remove enough of the energy of the molecules of a liquid and they begin to take up a pattern and 'crystallise'. When the crystals are melted how do we know that the pattern completely disappears? The answer appears to be that it quite often does not. Professor G. W. Stewart[3] was the first to draw attention to the fact that where it was possible to obtain X-ray diffraction patterns for both the liquid and the crystalline states of a substance there was a general resemblance between them. In the case of a crystal the pattern is formed by the scattering of a pencil of X-rays by the regularly spaced atoms, and it would be thought that the molecules (and thus atoms) of a liquid would be distributed in so random a manner that no pattern would be produced. This proves not to be so, although the pattern is far less easy to detect than for the crystal.

Following up this lead Professors Bernal and Fowler in 1933 published a long paper[4] on the constitution of water. They considered a wide variety of evidence including the X-ray scattering effects and they were able to conclude quite definitely in favour of a particular kind of 'quasi-crystalline' structure for water near its freezing point. Their views fit in well with Stewart's theory that liquids have a 'cybotactic' structure, viz., that there are small aggregates of molecules arranged as they would be in a crystalline particle. Thus in water the same pattern which is found repeated in all directions in the ice crystal *is* present in water even though it extends over only a limited number of molecules at a time.

The pattern is constantly forming and vanishing at any given point so that on the average only a certain degree of order prevails.

A new theoretical approach has therefore been made to the subject and it is supposed that a molecule is 'all the time within a field of force of about as many other molecules as in the solid phase; it does not, as in a gas, spend most of its life in comparative freedom and interact strongly with other molecules only occasionally'.[5] Although the picture is not yet very clear the results from the experimental and theoretical sides seem to be in general agreement. Useful evidence can for example be obtained from the study of glasses, which are simply liquids cooled down below their freezing points but without crystallisation having taken place. It is as if the particles of the liquid had been frozen in their positions so that they can be studied at leisure. (No doubt it is not really quite so simple as that.)

It must be emphasised that an article of this size and scope cannot do more than present a general picture. But enough has already happened to make it quite certain that the old kinetic theory of liquids is quite inadequate. For the specialist there is a large review of the subject by the Russian physicist Frenkel.[6] Frenkel shows repeatedly that we must give up the belief that the physical and mechanical properties of liquids are radically different from those of solids, and indeed the present position is that liquids have as much or more in common with crystalline solids as they have with gases.

Quite inevitably the new view of the liquid state has meant a considerable change in the explanation of viscosity. In a flowing liquid it is now supposed that some of the momentum of one layer is transferred to the next (i.e. in laminar flow) through the operation of transient molecular forces of the sort found in crystals. On the older theory, molecules were supposed to be lost from one layer to the next, and it was this which was supposed to bring about the transfer of momentum. It is clear that the loss of faster-moving mole-

cules to a slower-moving layer would have this effect. Frenkel, and in this country Professor Andrade, have worked out theories of viscosity which are more in line with the new ideas. As Professor Andrade expressed it, on the supposition of a 'transitory and fluctuating crystallisation,' or a temporary holding of hands between individuals of two parallel rows moving past one another, a theoretical equation can be derived which holds good for the viscosities of quite a number of elements in the liquid state. This equation is

$$\eta = K \sqrt{\frac{A\,T_M}{V_A}}$$

where A is the atomic weight of the element, T_M the melting point on the absolute scale of temperature, V_A the volume of the atomic weight expressed in grams and η the viscosity. The constant K has the value $5{\cdot}1 \times 10^{-4}$. A modified equation can be applied to those liquid *compounds*, the molecules of which have sufficiently uniform fields of force around them.

Unfortunately water remains too difficult a problem. The water molecule possesses a field of force which is by no means uniform, and as Bernal and Fowler have shown the amount of 'order' in the liquid is relatively high. It would seem that the existence of cybotactic units must interfere with laminar flow as conceived in the simplest way. The consequence is that there is as yet no complete physical theory for the viscosity of water. Much work has been done, however, on the effect of dissolved substances such as salts.

The initial effect of all salts in very weak solutions seems to be to raise the viscosity. It is known on other grounds that the ions into which salts are dissociated have considerable restraining influences on each other's movements, and viscosity measurement of salt solutions does provide in fact a useful means of examining inter-ionic forces. The ions of salts are surrounded by large numbers of water molecules

which orientate themselves in the electrical field of the ion. There are, besides, ions of opposite charge always in the vicinity. The result is an ionic atmosphere which is constantly shed and rebuilt as the ion moves through the liquid. The effect on the viscosity of the solution has been calculated, notably by Falkenhagen, and some agreement between theory and experiment can be recorded.

It is something of a relief to turn to the solutions of non-electrolytes in solvents other than water, for here the conditions are a good deal simpler. Here we almost certainly approach the state of affairs envisaged in Andrade's theory. The molecules of the dissolved substance affect the viscosity in a way which depends in a relatively simple manner on their size and shape. Staudinger, for example, uses the viscosity of a solution (e.g. in tetralin) in order to compare the lengths of molecules. Thus he has shown that the relative alteration in viscosity

$$\frac{\eta\text{ solution} - \eta\text{ solvent}}{\eta\text{ solvent}}$$

depends directly upon the concentration of the dissolved substance and the size of its molecules. Provided the substances compared are of the same chemical type the method gives a quick means of comparison of the sizes of molecules produced in the important process of polymerisation. In polymerisation the chemist is causing small molecules to join up, usually in a head to tail fashion, to produce very large molecules, and in the production of lubricating oils and in the formation of substances for use in plastics this is of great economic importance.

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Group Psychotherapy

STEPHEN LESTRANGE

DURING the last generation the treatment of the mentally sick has made great advances. No longer does the onset of serious mental illness mean the incarceration and the custodial care of the patient pending a possible spontaneous recovery. Instead, there is an almost universal counsel of hope and active therapeutic measures are available. The dramatic empirical success of the new physical treatments – electrical treatment, insulin therapy and 'Mind Surgery' – must not be allowed to obscure the more solid advances which have been made in the understanding and treatment of the milder forms of mental illness. Mental illness – 'Insanity' – still has a great deal of stigma attached to it, but with the increase in knowledge of the function and structure of the normal mind, and the realisation that even the most polished intellect is flecked with emotional bias and miniature pathological reactions, people are more willing to go to their doctor with what they used euphemistically to call their moods, turns and eccentricities. Doctors in their turn realise more often that nervous symptoms can and should be treated.

Knowledge of the how and why of mental disorder first began to take scientific shape with the work of Freud at the end of the last century. Even now, fifty years later, so subjective is the nature of the material that argument still rages round many of the early findings, and the body of knowledge which is widely accepted or open to direct proof remains extremely small. Freud recognised that neurosis was largely, if not entirely, a price that was paid for civilisation and the many advantages gained from a complex social organisation. Most of his investigations led him to the study

of mental development in the very circumscribed life of the infant and its conflicts with a hostile or indifferent environment. The infant is intensely individualistic; he has no knowledge of, nor does he care about, the needs of others. At his first breath he is a pulsating but powerless bundle of life incapable of fending for himself or even of expressing his needs save by indiscriminate signs of distress. Fortunately his wishes are satisfied almost before they arise. Surely, then, here is a being completely dependent on others; he is unaware of this, however, and feels no obligations in return. It is the age of omnipotence.

The Freudians unfortunately interpret the consciousness of the newborn in terms applicable to our adult minds but which can bear little direct relationship to what the infant may be thinking – even if his mental processes bear any resemblance to those of adults. Whatever the conscious concomitants, however, it remains true that as the infant develops he has to give more and receive less: the world no longer revolves around his whims and there are other human beings whose needs and desires involve the postponement or loss of his own satisfactions. Meals must await the arrival of others and a kind word, if he is lucky, replaces a prolonged caress. Fears, beliefs, modes of reaction which are developed at this early stage lie deep in the formation of his character and are hard to change. They will, however, influence him throughout his life. These patterns of behaviour are forgotten – 'repressed' – and they are synonymous with the unconscious forces of the Freudians.

As the child grows up there are continually problems of social adjustment facing him at a conscious level: Playmates – School – Parties – College – Work – Leaving Home – Marriage – these are all milestones in the development of his ability to handle interpersonal relationships; throughout life there is a continual adjustment to society. Living in a civilised community is not all electricity and drainage, and the price to be paid is not merely the rates. Civilisation involves the continual suppression of antisocial trends, the

inhibition and redirection (sublimation) of many primitive drives, especially those of aggression and sex. There must be a continual modification of the individual's wishes and behaviour in order that he may avoid conflict with his fellows: a kind of thermostatic control, with the regulator set at a conventional level of permitted self-seeking. This control mechanism may break down in several ways. The individual may refuse, for instance, to accept the sacrifices imposed by the community and become a criminal or a revolutionary. More often open conflict is unsought, and arises either because of a constitutional weakness of the personality or because the problem to be solved becomes too great. This failure to control the situation leads either to mental illness, or the stress may cause apparently physical disease such as peptic ulcer or colitis. In the causation of mental illness external strain generally interacts with a poor personality structure. The balance between these two factors is well illustrated by the experience of war-time. Here the external stress is increased and may become so great that the most stable personalities will react with marked neurotic symptoms.

Illness begets its own treatment. Psychotherapy is the combined attempt of the patient and his physician to unravel the causes of the conflict and attain an understanding of the underlying basis of the symptoms. Relief through psychotherapy can be obtained by three main methods.

Removing the cause: many of the aetiological factors lie in childhood or even further back – in the inherited make-up of the patient – and it is of course impossible to remove these. The burden of real and present troubles is, however, often a large one, for the neurotic tends to accumulate failure. Adjustment of the environment is therefore an important part of the treatment of the patient and it is the plaint of the social worker not that there is so little to do, but that it is so difficult. A patient who suffers from claustrophobia may find the long journey to work in a crowded train a terrible ordeal. His impulses to jump from the

compartment may become so strong that he no longer dares to make the journey and he stops off work. Financial worries now add to his misery. The treatment of claustrophobia may unfortunately be long drawn out and the social worker must step in to fill this gap. She is not content with helping the patient to obtain financial aid from the appropriate authority or charitable institution. Bread and butter may be essential for the patient's existence, but self-respect is just as fundamental to mental health and the social worker should find the patient similar work near his home. Alternatively, she can help him to obtain accommodation within walking distance of his original job.

Altering the patient: Many conflicts are due to reactions more relevant to the child than the adult; or they may be due to false beliefs which the patient has acquired early in life and which colour his picture of reality. To take a simple example: boys are often brought up to believe that women are different – angels in thought, noble and unsullied by the unpleasantness of life's struggle. This is known to psychiatrists as the error of the pedestal. Alternatively, the contrary delusion is equally common – that women are scheming, false and a certain ruin to the man who meddles with them. This is known, perhaps a little more cynically, as the error of reality. Both these errors are typical of the misconceptions a patient may have about reality. They are a type of fallacy inherent in human thought – generalisations from the particular and exaggeration of the importance of what we happen to have experienced ourselves. These fallacies do not easily suffer spontaneous correction, and for two main reasons. First, they are often beliefs stamped early into the mind of a child by a parent. To the child, the words of a parent or parent-surrogate have all the authority of the *ex cathedra* statement of a being who is at one and the same time the most feared and the best-loved person in the world, and whose omniscience has not yet been questioned. To deny these beliefs is to deny the parent himself, and however emancipated we may feel this arouses immense

unconscious resistance. Secondly, these fallacies are almost always half-truths, and there is consequently a lot of evidence to bolster them up: women are good and they are evil.

One further example of a type of misconception of major importance is that children are almost always taught absolute standards of right and wrong. Their criteria of ethical behaviour are often excellent, but the ideals are unfortunately painted in strong blacks and whites and much unnecessary conflict is engendered by this distortion. The man who believes that women are pure is unable to reconcile this with the reality of a human help-meet who, for his sake, cheats the milkman and jeopardises the rationing scheme. If, on the other hand, he regards women as the embodiment of evil, desire continually wars with fear. If we believe that virtue is absolute, it is disheartening to find ourselves always among the goats. Man has a need of virtue and a sense of right-doing, and if he is to keep going happily he must feel that some of his arrows are falling near their target, or at least travelling in the right direction.

This, succinctly, is our second point: the patient is struggling to fit comfortably into a niche in the external world. If his picture of reality is blurred and false he will find this more difficult – perhaps impossible. Here the psychiatrist can help him. Any intelligent onlooker can point out the foolishness of these misconceptions (they are not called delusions because so many normal people subscribe to them), but the neurotic is shy of rational argument and the only effective approach is by demonstrating to the patient how these ideas originally arose and how they gained the power they undoubtedly possess. Better still is the analytical method of leading the patient back over his life and letting him discover these early influences for himself.

I mentioned three main methods of treatment. We have already created a dichotomy – our patient and his environment. Our third approach therefore must embody the other two. We call it adjustment; fitting the patient into the real

world. Having made our assault on the environment (social therapy) and having altered our patient (individual therapy) we do not, unfortunately, find an easy fit. Bluntly, he must lump it, and we must help him. This is supportive therapy. We can help him to develop his assets, seize his opportunities and learn acceptable methods of gaining self-esteem and satisfaction. Like a patient with heart disease, he has to be taught to live within his limitations. Briefly: no moon and no tears. Critics of psycho-analytical technique say that what is not nonsense is common sense. Of course this is true and one is tempted to reply with the adage that common sense is an uncommon virtue. Sense, that is to say, rational thought, is a treasure that is available now and again to everyone, but never continually to even the most critical. Most problems in living – those between persons as well as those between nations – have a sensible solution, but it is a matter of common sorrow that this is so rarely applied. No psychiatrist is himself perfect, but he is a specialist in interpersonal relations. In a world where perfection is only a rumour the lame can sometimes teach the paralysed to limp.

One of the limitations of psychiatry has always been the amount of time which the therapist should devote to each patient. Orthodox psychiatrists may devote several hours to the investigation of one case, and treatment may entail many more. An analysis may require two or three hours a week for a year or longer. A second limitation is that the patient's problems are often ones of social adaptation. He sees his doctor in private, however, takes his advice to heart and goes away to try and put it into practice. How much better it would be if his doctor could see him in his trouble and try to help him adapt on the spot. Both these limitations are removed to some extent by group psychotherapy. This implies that a group of patients is treated together rather than individually. It is not however merely several individuals receiving treatment at the same time. For the patient the group is an entirely different situation

from an individual treatment session. His mental orientation is altered by the need to consider the other patients, and he forms emotional ties with them as well as with the therapist. This group situation brings to the forefront social urges which many psychologists would attribute to a primary instinct – the herd instinct; it is in fact an attempt to reconstruct the social pattern in miniature.

Originally, group treatment was used to expedite the after-care of patients with physical complaints. The first recorded use of group therapy was the experiment of Dr J. H. Pratt in Boston. In 1905 Dr Pratt arranged a series of meetings for a group of tubercular patients and gave them formal instruction in hygiene and careful living. The original impetus for the experiment was a desire to save time, but Pratt soon noticed that the patients enjoyed meeting together and gave each other mutual encouragement. He was not slow to develop his discovery and soon started groups for the treatment of other chronic diseases, such as raised blood pressure and diabetes. So successful were his results that his methods were quickly adopted by workers in other parts of America. In the field of mental illness the benefit of group activities had been noticed earlier. In 1904 Dr Camus and Dr Pogniez working in the Salpetrière (Paris) published a report on their experience with the prolonged rest treatment devised by Dr Weir Mitchell. They noted in passing that the patients in the large public wards were considerably more cheerful than the patients treated in private rooms. These workers however did not appreciate the importance of this observation, and the credit for the first conscious use of group psychotherapy must go elsewhere. By 1909 Dr Marsh was experimenting in America with the group treatment of the psychoneuroses. In Vienna in 1911 Dr Moreno began his famous experiments with problem children. He treated these patients, too young for formal analysis, by methods analogous to play therapy. He encouraged the children to act out their fantasies in miniature plays, and thus laid the foundations of psycho-

drama. These methods soon caught on and it became clear that patients who received group therapy showed greater improvement than those treated individually. They were getting something extra. What is the cause of this extra benefit ?

Psychotherapy has two main weapons – a direct appeal to the intellect and an indirect approach through the emotions. The emotional situation which arises between doctor and patient is far older than the study of psychological medicine and has in fact always played a part in medical treatment. In psychotherapy this emotional bond assumes a very important rôle and has been dignified by the special name of 'transference'. The formation and subsequent control of a 'positive' (helpful) transference between the therapist and his patient is one of the most difficult aspects of psychotherapy. A positive transference is easily acquired to start with, but as treatment progresses and the patient is faced with unwelcome home truths and the loss of some of the protection he obtained from his illness he evinces marked hostility. This is the stage of 'negative' transference and unless it is handled carefully he may break off treatment. Even a favourable emotional situation can sometimes interrupt treatment as effectively as it can aid it. A crucial point in psychotherapy is the careful dispersal of the therapeutic transference when the treatment is drawing to a close. Mistakes here will lead either to a pathological dependence on the analyst or to a sudden loss of all the ground so exhaustingly gained. It is in its different approach to the transference situation that group psychotherapy makes an important advance.

The basis of the emotional life is very imperfectly understood, but it is clear that normal people have a great need to love and be loved. Part of this emotional pool is used up on individuals – parents, siblings, spouse, friend, lover – some of it is directed towards groups of people – the village, the office, home and country; or even towards symbols or abstract conceptions such as the flag or democracy. It

seems obvious, and practice appears to bear this out, that group treatment offers a more natural environment for the adjustment of some emotional disturbances than does the intense focal point of individual analysis. Group therapy also enables the patient to form more diffuse and less intense emotional ties while under treatment, and he is spared the necessity of switching them on and off suddenly. Friendships formed in the group may be continued into everyday life. Group therapy is not a comprehensive panacea and should be part of a wider therapeutic plan. First the patient should be given a lengthy diagnostic interview at which a comprehensive history of his illness and the background of his life is recorded. This should be followed by a thorough physical examination to exclude or evaluate any organic disease If any doubt remains, special pathological tests will almost always settle the point. Only when the patient has been thus diagnostically assessed is it possible to lay down a rational plan for treatment. Group therapy may be the main treatment suitable for a particular patient, but even so it must be supplemented by individual therapy. Such individual treatment should if possible be given by the doctor who runs the group. On the other hand, group therapy may be an adjuvant to the physical methods of treatment.

The conditions which benefit most from group psychotherapy are the psychoneuroses – particularly anxiety states and reactive depressions and the psychosomatic illnesses such as peptic ulcer, high blood pressure and asthma. In these latter conditions worry and tension aggravate the organic lesion if they do not actually cause the physical changes. As every member of the group will influence the progress of the others, the selection of patients suitable for a group requires considerable clinical acumen. The inclusion of one unsuitable patient may completely disrupt the group and block further progress. On the one hand, the acutely disturbed or deeply depressed patient will distract and upset those less ill. On the other, the supercilious, argumentative

intellectual will spread a highly contagious atmosphere of non-cooperation. It is not essential that all the patients start at the same time, and in practice it is found helpful if a new patient joins a pre-existing group: old members make him welcome and explain the mysteries to him. Those who have never had any psychotherapy before resent the idea that their troubles are primarily mental and are inclined to doubt the efficacy of mere talk. The personal story of recovery from symptoms very similar to the new patient's own, told by one of the old members, carries more conviction than all the blandishments of the most enthusiastic psychotherapist. The latter also appreciates the piecemeal arrival of his clientèle because it gives him an excuse to reiterate his fundamental concepts.

The number of patients admitted to a group depends on the type of treatment. The 'deeper' the therapy (i.e., the more analytical) the smaller the number which can be satisfactorily treated. Two or three patients treated together will automatically form a group, while eight to twelve is probably the ideal number. With more than twenty members the session is likely to degenerate into a lecture and while this didactic form of treatment can still be very helpful, it lacks the plasticity of a small integrated group. At the first session, then, the therapist will find himself surrounded by headaches, backaches, giddiness, weak legs, indigestion, palpitations, depression, tremors, paralyses, pains before the eyes, pains behind the ears, pains all over and just plain nerves. With examples and explanations in simple terms the therapist shows how symptoms like these can be caused by mental conflict and worry. He draws everyday analogies to illustrate these mechanisms at work. Fear, he reminds the group, can cause sweating, trembling, nausea and diarrhoea – physical symptoms; a sudden shock – even the mere sight of blood – may cause loss of consciousness; tension and awkward postures cause muscular discomfort and pain. He emphasises that rigorous medical examination has excluded any physical cause for their symptoms and

leaves them to draw their own conclusions. The therapist proceeds to give a short series of lectures on simple psychological mechanisms. He will explain how we repress unpleasant ideas and how the emotions attached to them may still influence our thoughts and actions. When the patients have become used to each other and have acquired some knowledge of psychological mechanisms they are required to write their own life stories in the light of this new knowledge. Selected passages are then read out – anonymously – and everybody is invited to comment on them. It is illuminating, but not altogether surprising, that patients will often recognise more easily in others than in themselves the psychological causes of symptoms. Making this step, of course, helps considerably towards the attainment of insight into their own troubles. Throughout group treatment the patient is seen individually at frequent intervals when the more personal points and intricacies of his own illness are discussed.

In many clinics this fundamental educative side of the treatment plays a minor rôle and most of the benefit is derived from the emotional re-adjustment obtained. Many patients have never really attempted to integrate their lives with their neighbours: social conventions have dammed back the primitive expression of their drives and they have never acquired the ability to enjoy the compensating outlets that civilisation offers. Other patients have become so preoccupied with their symptoms that they have withdrawn from social activities. The psychotherapist therefore attempts to establish a communal organisation; he encourages the patients to take up hobbies and to develop any interests they have in common. He lays emphasis on the duties of the individual to the community, encourages co-operation and friendship between patients, and by pointing out how everyone can contribute in some way to the general good, bolsters up their self-respect. He teaches them muscular relaxation, which besides having a beneficial physiological effect renders them more suggestible and paves the way for

the acceptance of encouragement and reassurance. Many therapists, especially in America, conclude each treatment with exhortative passages from the poets and minor philosophers. The more inspirational a therapist's technique the more closely does a group session resemble a revivalist meeting. Indeed, such movements as the Oxford Group use similar methods. 'Alcoholics Anonymous,' a group formed by alcoholics for the treatment of alcoholics, emphasises that a fundamental step towards the success of their treatment of the chronic drunk is a change of face equivalent to a spiritual conversion. The mass cures, which in the past accompanied outbreaks of religious fervour, were spontaneous examples of the mechanisms underlying group psychotherapy. Special methods such as psychodrama are extensions of the same principles. The patients themselves act out their conflicts and seek solutions in imaginary situations.

In assessing the results of group psychotherapy it must be remembered that it is the chronic neurotics who respond best and these patients are notoriously unresponsive to other methods of treatment, usually continuing in a state of interminable disability. The modest achievements which can truthfully be attributed to group treatment are therefore a decided therapeutic advance. In one follow-up questionnaire 90 per cent of patients replying said that they had improved, and most of these to a considerable extent. When allowance was made for those who did not reply, and for those who had defaulted from treatment, the proportion showing improvement fell to just under 50 per cent. Group therapy takes deliberate advantages of man's gregarious nature, and is thus planted on a firm theoretical basis. Further, it has stood the test of time. It can therefore safely be added to the armamentarium of the psychiatrist, but it must be remembered that group therapy is not a specific and when further light has been thrown on the ætiology and pathology of the neuroses it may well give way to a more direct method of attack.

Research Report

A. W. HASLETT

Muscle measurements.

FOR sheer delicacy of measurement and finesse of experiment it would be difficult to beat some recent observations by Prof. A. V. Hill of University College, London, on the heat changes which take place during a single twitch of a muscle. The rise in temperature which accompanies such a twitch is only about 0·0025 degrees Centigrade. This in itself would present no particular difficulty, for although it represents a small enough temperature change by ordinary standards, very much smaller differences in temperature can be measured. The real difficulty was that, in order to follow a single muscular twitch through all its stages, and particularly to record accurately its beginning, Prof. Hill needed to measure both the contraction of the muscle and its temperature at such speed that the state of affairs at intervals of time only two thousandths of a second apart could be distinguished. It was the combination of these two requirements of speed and sensitivity which made the measurement problem difficult.

The first stage was to translate the temperature changes to be measured into changes of electric potential. This was done by a small electric thermometer or thermopile about as thick as a red blood cell is long. Its maximum output, under the conditions of the experiment, was about four millionths of a volt. This in turn was translated into a small movement of a mirror attached to a fine wire coil suspended between the two poles of a magnet. In outline this is a standard arrangement. The idea is that a beam of light is directed on to the mirror, and the deflection of the light beam when the mirror moves is observed on a distant scale,

The details of the magnification system which Prof. Hill employed cannot be given. But the effect in the final display was as if the light beam from the mirror had been observed from a distance of some 285 yards down the road. And the main point was that to stand such enormous magnification and at the same time give the required high speed of response, and steadiness of movement, the mirror system had to be almost perfectly balanced and provided also with a form of mounting which was almost completely immune to outside vibration. The key part of the instrument was constructed in Prof. Hill's laboratory by Mr A. C. Downing.

The measurements, about which all this trouble were taken, were made on the leg muscle of a frog at a temperature of zero Centigrade. Under these conditions, the contraction period of a single twitch was spread out over about 0·4 seconds, and the following period of relaxation lasted about 0·6 seconds. And to recover to its original state, the muscle required some 45 minutes.

No new or sensational theory of muscular action has been put forward on the strength of these measurements. Merely, a few concrete facts have been brought together which any future theory will have to explain. One is that, although the muscle takes from 7 to 10 thousandths of a second to 'get going', it is impossible to separate in time the beginning of the release of heat and the beginning of the physical movement of contraction in the muscle. The two effects are simultaneous within the two-thousandths of a second accuracy of the experiment. Second, the release of heat appears to take place straight away at its maximum rate. The effect is as if the muscle was already 'set up', ready for action, and needed only to be released or 'triggered' by a nerve stimulus. Third, there is the peculiar fact that in a single muscular twitch, the initial release of heat in contraction is independent of the amount of physical work done by the muscle. 'It would be a very odd kind of cartridge,' as Prof. Hill has said, 'in which the energy released in the explosion had no apparent connection with the muzzle

velocity of the bullet.' And finally, there is no sign of the absorption of heat, as opposed to its release, at any stage of the complete cycle of contraction, relaxation and recovery. Negatively, this seems to disprove fairly decisively one theory of muscular action which has been much discussed. But neither is there any other complete or consistent theory which can be put forward. Prof. Hill, who should know, thinks that the time is not yet ripe.

Hill, *Proceedings of the Royal Society* (in the press).

Coral island.

One of the advantages of research conducted for the United States services is a certain lavishness of effort, with a tendency to follow up sidelines which are of more interest for their own sake than for their ostensible purpose. An example was the explosion of the Bikini atom bomb which, among other activities, led to the deepest boring yet undertaken on any coral island. A report which has lately been issued shows that this was carried to a depth of 2,556 feet, and it is seriously suggested that an 8-10,000 feet boring should now be made. Also, a large number of deeper soundings were made by the method of setting off explosive charges near the surface and observing the times at which earth waves were recorded at different points on the atoll.* By this second method it was established that the depth to basement rock was about 8,000 feet in the centre of the lagoon, but there were variations of many thousands of feet in the corresponding figures for different parts of the complete atoll.

The interest of what was done at Bikini, and still more of the proposed deeper boring, is in relation to theories of the growth of coral islands. The picture which is still, in the main, generally accepted is that which was first put forward by Charles Darwin on the strength of observations which he made during the same voyage of the *Beagle* which led him to his more famous theory of evolution. This was the first attempt to cover in a single theory the three chief forms

of coral growth. These are the fringing reef, the barrier reef, and the atoll or coral island. By the first of these is meant the type of reef which grows directly out from the coast and at low tide can be seen to be connected with it. The barrier reef, on the other hand, looks to be a separate structure from the continent or island which it separates from the ocean beyond. The Great Barrier Reef of north-eastern Australia stretches for about a thousand miles, acting as a more or less continuous breakwater separating Queensland from the Coral Sea. On the other hand, in the typical barrier reef island, the barrier reef is an irregular circle, with the island in the middle, and usually a break in the reef on the leeward side, and safe anchorage in the lagoon between reef and island. Finally, in the atoll or coral island (in the literal sense) there is no central island, but only a broadening of the coral reef on which vegetation has become established.

Darwin's suggestion was that, in the typical case, these three types of formation could be regarded as stages in a single process. He supposed that the original island was volcanic, as many Pacific islands obviously are. In the first stage, he thought, a fringing growth of coral would become established round the edge of the island – although, in fact, there are no known examples. Then, in the second stage, the island would begin to subside, and the reef would grow upwards to keep pace with the subsidence, but would now be reared above a part of the island which was submerged, giving the effect of a barrier reef. Finally, in the third stage, the original island would have subsided so far as to have totally disappeared, and only the barrier reef to which it had given rise would be still visible above the surface.

The theory is attractive in its simplicity, but fails completely to explain one further fact – that the depth of nearly all atoll lagoons lies between about 120 and 240 feet, with a relatively flat sea bed at that level. There is no obvious reason why every subsiding volcano should consistently stop subsiding when its summit is at the same depth below the

surface. Nor can the theory, by itself, account for the very large amount of debris needed to level off the gap between the sloping sides of the former volcano and the barrier reef. It was therefore pointed out by the American geologist H. A. Daly that during the period when the continents of Europe and North America were covered in ice sheets, the level of the oceans would have been lowered by some 300 feet. During this period, any pre-existing coral would have been unable to survive, and he thought that the effect of waves and storms would have been to wear away the top of the island to a roughly level platform. Then, about 25,000 years ago, when the level of the oceans would have begun to rise again, from the melting ice of the continental sheets, coral would have become established round the edge of these eroded platforms, and the final result would be a barrier reef, with a central lagoon of roughly the required depth. It is against the background of these two theories, which many geologists believe can be usefully combined, with the possibility of more violent movements at intermediate stages, that the results of test borings through deep coral structures are most naturally considered.

Fifty years ago, the first such boring was undertaken by the Royal Society on Funafuti atoll 500 miles north of Fiji, and since then there have been further borings on the Great Barrier Reef of Australia, in the East Indies and in the island chain south of Japan. But by a substantial margin there has been none so deep as that lately carried out on Bikini atoll, nor was there the same information about the depth of the basement rock. Only the preliminary results of the Bikini boring are yet available. These bring out two main points. The first is that the layers of the atoll foundation which are now 300-575 feet below sea level appear to have been at one time exposed above sea level. This suggests that, as well as the two main processes, there must at one stage have been a quite considerable upheaval. The second is that the layers from 1,790 feet down to the lower limit of 2,556 feet are lower miocene and must have been formed

therefore between 20 and 30 million years ago. This would imply an average rate of growth not more than one-thousandth of the maximum rate of a foot in ten years which is possible for coral structures. In other words there would be an ample margin for interruptions and reversals of movement. Consequently, if money, time and equipment, can be made available it would be a project of real interest to explore a single deep structure down to and into the basement rock beneath. The suggestion is that the boring should be in the centre of the lagoon, so as to give the earliest chance of reaching the basement rock; and that, in conjunction with a sunken landing barge, the existence of a number of flat-topped platforms reaching within twelve feet of mean sea level, would make such a central boring possible.

Ladd, Tracey and Lill. *Science*, 1948, *107*, 51.

Radar and colonial survey.

Methods of mapping from the air, with radar control to fix position, which were developed during the war for use in the Far East, are now being applied on a large scale in Africa by the Colonial Survey Organisation. Since April of last year upwards of 150,000 square miles have been photographed in this way. This includes the whole of Swaziland, and parts of Bechuanaland, Tanganyika and the development areas of Uganda, as well as some further work in Kenya. Priority has been given to those areas scheduled for ground-nut planting, and the whole programme has been tackled with a speed and urgency which would have been impossible with conventional methods of surveying. There is also the advantage that, pending the translation of air photographs into maps, the photographs themselves are immediately available for any purpose for which large numbers of copies are not required. These are on a scale of 1 in 30,000 – or not quite two inches to the mile. Mapping from the air photographs is limited at present to a rate of 80,000 square miles a year, so that the bottleneck is on the

mapping side rather than in the taking of the photographs on which the maps are based.

The system of radar control is based on measurements of the range of the aircraft from radar beacons installed in convenient positions on the ground. The main transmitter, with a system of this kind, is in the aircraft, and the beacons on the ground can be thought of as so many reflectors from which radar echoes are returned to the aircraft. This is the reverse of the original air-warning use of radar, when the transmitter was on the ground, and the echoes which were measured came from the aircraft. The only difference otherwise is that instead of relying on simple reflection, the radar beacons are provided with auxiliary transmitters which are triggered or 'set off' by the aircraft transmissions, thus giving stronger reply signals. The measurement which is obtained is that of the range of the aircraft from the beacon, and it is usual in survey work to fly on a series of circular courses about one of the beacons. In this way, if photographs are taken at regular intervals of time, and successive courses are accurately spaced, it is possible to make certain that there are neither gaps nor overlapping. With the addition of a second beacon, or ground station, the position of the aircraft is fixed. The ranges of the aircraft from both are directly displayed, and arrangements are made for a photograph to be taken of the instrument panel showing these two ranges, the height of the aircraft and the tilt of the aircraft at the same instant that each survey photograph is taken. The earliest experiments with this method were carried out in Anglesey, and later the Colonial Survey Organisation carried out further trial surveys in West Africa. The present surveys in central and east Africa are believed, however, to be the first large-scale application to practical mapping. The limit of accuracy is stated to be about 75 yards.

Prof. C. A. Hart of University College, London, who was lately appointed to the first university chair of surveying and photogrammetry, was directly concerned with the

earlier wartime development which led to the present application in Africa and is continuing research on the still more accurate development of radar control methods. An appreciably higher standard of accuracy is, in fact, already attainable – but the equipment is neither so simple nor so mobile as that used by the Colonial Survey Organisation. Also as might be expected, the amount of work required in translating air photographs and radar control measurements into accurate maps increases considerably as the standard of accuracy is pushed up. There is therefore a substantial gap technically between the type of survey which is now being carried out in Africa, and the revision of home Ordnance Survey plans, on which there are heavy arrears waiting to be caught up. At the largest scale used by the Ordnance Survey, an error of 75 yards would represent a distance of about two-thirds of an inch on the final plan. There seems little doubt that Ordnance Survey standards could be reproduced by a combination of radar control and air photography. But although this may be possible technically, it would clearly be unwise to assume that, because the radar method is rapidly proving itself in Africa, the ground surveyor and his traditional 'chain' have been rendered universally obsolete.

Radio and the sun.

Radio methods of observation look like giving new information about sunspots. It has been known for some time that abnormal bursts of radio radiation appear to come from the direction of the sun at times when the sun's disc is unusually disturbed – that is, when there are many or large visible spots – and it has been calculated by Sir Edward Appleton that, under these conditions, the sun is the most powerful radio transmitter of which we have knowledge. It was left, however, for M. Ryle and D. D. Vonberg at the Cavendish Laboratory at Cambridge to make the first measurements of direction sufficiently accurately to enable an estimate to be made of the width of

the active area on the sun's surface. They found that, at the most, the width of this area could not be more than about ten minutes of arc, or some 300,000 miles on the sun's surface. Any error in their measurements would have made this an over- rather than an under-estimate – and as a spot measuring not quite 150,000 miles across was visible at the time, it seemed a reasonable guess that the visible sunspot and the observed 'radio spot' covered roughly the same area. Since then, the sun has been kept under continuous radio observation, in quiet times as well as disturbed, over a period of some ten months. Records have been made on two different frequencies, 80 and 175 megacycles respectively, corresponding to wavelengths of 3.75 and 1.6 metres. And it has been found that one useful indication of conditions on the sun is the proportion of energy which is put into these two frequencies. Under disturbed conditions, the amount of power radiated on the higher frequency is several times greater in proportion. Finally, taking this change in energy distribution as the criterion, it was noticed that there was a tendency for these abnormal periods to recur at 27 days intervals, corresponding with the sun's known period of rotation. This, in itself, is not particularly surprising. Sunspots themselves are liable to recur at similar intervals and for the same reason, although it is unusual for even a large sunspot to make more than one or possibly two repeat appearances. What is interesting, and rather surprising, about these Cambridge measurements is that, during the whole of this ten months' period, there seem to have been only three main areas of activity on the sun. One of these has survived for as many as 11 rotations, another for 7 rotations and the third for 5. It is early to draw definite conclusions, and Mr Ryle has himself pointed out that these results cannot yet be regarded as providing sufficient proof. But at their face value, they suggest that to the radio observer disturbed regions on the sun's disc have a very much longer life than they present to the astronomer; and that visible sunspots

should be regarded as only one stage in a longer history of disturbance, of which the earlier or later stages cannot be seen.

Ryle. *Nature*, 1946, 161, 136.

Film of the sun –

Considerable and well deserved attention has been attracted among astronomers to a film of the sun made by Prof. H. D. Menzel at the Climax, Colorado, high altitude observatory of the Universities of Harvard and Colorado. A copy of the film has been presented to the Royal Astronomical Society and this has been shown lately in London. It was taken through a special type of filter and shows the behaviour of prominences seen at the edge of the sun's disc. The general effect can only be described as that of a fireworks display on an immense scale, originating in a surface of almost continuous disturbance and movement, and with a variety of forms which any manufacturer of fireworks could only envy. These included narrow luminous jets, shooting rapidly outwards and looking (probably deceptively) to return along the same line on which they had started out; a great eruptive surge, developing into a luminous mushroom spreading outwards from the sun's disc; a cloud suspended, as if held in its place by electrical forces; and an inverted cone, in much the same shape as an umbrella blown inside out by the wind. It could be seen also that many luminous 'shoots', for example between one cloud and another, followed curved courses as would electrically charged particles if moving under the influence of strong electrical or magnetic forces; and, visually, at least, one got the impression that inward moving streamers were being sucked into particular areas on the sun's surface. Films of this kind, taken in broad daylight, of events at the outer edge of the sun which would normally only be visible during total eclipse, were first made by M. Bernard Lyot, the French astronomer. Prof. Menzel's set a standard which will take some beating – although, naturally, the ultimate value of such a film is not in the visual effect which

it produces on the spectator but rather in the mass of information which it provides for the formulation and checking of theories of solar activity. From that point of view, the dominant impression must be that conditions on the sun are not so simple as the contributions of theoretical astrophysicists would sometimes suggest.

– and of Penguins

Another scientific film which was shown lately in London was made as part of the work of the Falkland Islands Dependencies Survey. It includes a series of motion studies of Adélie Penguins, which, in the hands of competent zoologists, should be a useful supplement to the extensive observation made earlier by Levick on the same species and recorded in his book *Antarctic Penguins*. Many shots are included of penguins jumping from sea on to land ice, with an angle of take-off of about sixty degrees, with a slide in toboggan position on the ice as the usual ending. Points which could be noted were the quickness of pick-up to an upright position, and the balance shown afterwards in glissading, still upright, down a steep snow bank. Except immediately after a jump, they would use their tobogganing method for such a slope. But having jumped, slid and got up, they prefer to remain so. When the tobogganing method was used for straightforward travel on snow, with both feet and flippers used for propulsion, it compared very favourably with the similar efforts of a Weddell seal, humping its back like a caterpillar at each forward movement. So few zoologists have had the opportunity of studying the movements of penguins at first hand that it would seem well worth while making a slow-motion version of this and any further film studies of the kind which may become available.

Blood and its evolution

The red cells of the blood play so necessary a part in the conveyance of oxygen to all organs of the body that one

would have expected the manner of evolution of the blood pigments to have received more attention from zoologists than has so far been the case. Prof. H. Munro Fox, of Bedford College, London, is among the very few who have worked seriously on the problem, and he has lately obtained quite convincing evidence that the blood pigments should be regarded as biological accidents – that is, that having originally been used for some other function, the incidental advantage given by their oxygen-carrying capacity was then 'seized upon' by evolution and developed into one of the key attributes of all higher forms of life. The most obvious indication comes from the multiplicity of these pigments. Four different substances are known, which carry out this same job of oxygen transport. Three of them are compounds formed by the union of a protein with three comparatively simple iron-containing substances. The fourth, instead of iron, contains copper. A more precise indication comes from the water-flea *Daphnia* which, like a human being or mammals generally, may possess haemoglobin – but, at least in adult life appears to get along equally well with or without it. It has been shown in Prof. Munro Fox's laboratory that individual Daphnia can gain or lose haemoglobin within a few days; that they swim as vigorously when apparently 'anaemic' from its absence as they do when red-blooded; and that water from ponds containing red-blooded *Daphnia* can induce the development of haemoglobin in initially pale individuals from other ponds. Whatever reason, therefore, may have led to the appearance in *Daphnia* of haemoglobin, it cannot now be used for oxygen transport. Prof. Munro Fox's second piece of evidence was obtained during a visit to the Marine Biological Station at Naples. While working there he found, first, that there were families of marine worms of which some species contained haemoglobin, while others, closely related and living under similar conditions, contained a different blood pigment, chlorocruorin. Finally, he found a particular family, *Serpula*, in the members of which both pigments

were to be found in the same individual and at the same time. If both had been evolved in response to other and possibly different needs, and then found useful as oxygen-carriers, it would be an odd coincidence, but not in itself particularly unlikely, that both substances should be present in the same species. Haemoglobin could have originated through one process, and chlorocruorin through another, and both independently been pressed into service as carriers of oxygen. But if the need which was first filled had been that of oxygen transport it would be unlikely that two separate mechanisms would have become established, when either by itself was sufficient to do the job.

Fox, *Nature*, 1947, *160*, 431, 825.

Meson particles.

Twenty years ago, it was supposed that nature made use of only two kinds of fundamental particle as 'building bricks' for the construction of atoms, and so ultimately of the material universe. These were the negatively charged electron – the atom, if you like, of electricity – and the positively charged proton, otherwise the nucleus of the hydrogen atom, with a mass some 1760 times as great. To these, in 1932, Sir James Chadwick added the neutron, which was without electrical charge and of roughly the same mass as the proton. It was also discovered that positive electrons could exist as well as negative, and to match the positive electron it was thought possible that negative protons might also exist. But for almost a generation it was taken as axiomatic that no particles were likely to exist of masses intermediate between those of the electron and proton. There were electrons, the lightest particles known, and there were protons and neutrons – but nothing in between.

Then, in 1935, on purely theoretical grounds, the Japanese physicist Yukawa postulated the existence of an intermediate kind of particle with a mass about one hundred times that of the electron. No one at the time paid much attention because the existing picture appeared reasonably

cut-and-dried and, in the absence of experimental evidence, few contemporary physicists felt inclined to upset it. In 1937, however, Dr Carl Anderson of the California Institute of Technology produced clear-cut evidence for the existence in cosmic radiation – radiation, that is, reaching the earth from outer space – of a positively charged particle with a mass estimated at 200 times that of the electron. The real existence of meson particles had therefore to be accepted, and an enormous amount of experimental work has since been done on the observation of cosmic radiation mesons. Again, the tendency at first was to be conservative. Measurements suggesting that mesons might have more than one mass were critically examined, and reasons were found for distrusting the evidence, and for sticking to the simplest interpretation – namely that meson particles did exist, but that they could all be taken to be of the same mass. The pendulum has now swung for the second time in the opposite direction. At the University of Bristol, Lattes, Occhialini and Powell have shown fairly conclusively that there must be at least two meson masses, one twice as great as the other. And at Manchester University, Rochester and Butler have produced evidence pointing to a third possible meson mass, heavier than the other two – as indeed had been suggested by the French physicist Leprince-Ringuet a year earlier. Finally, there is a third suggestion, on much less direct evidence, of a considerably lighter kind of meson. All this is clearly going to take time to sort out. And the purpose of the present note is merely to place it on record that physics is once again becoming more complicated; and that not only do meson particles exist of mass intermediate between that of the electron and proton, but also that it is practically certain that mesons exist of more than one possible mass.

Lattes, Occhialini and Powell. *Nature*, 1947, *160*, pp. 543 and 486.
Anderson, Adams, Lloyd and Ross. *Physical Review*, 1947, *72*, 724.
Rochester and Butler. *Nature*, 1947, *160*, 855.
Auger, Daudin, Fréon and Maze. *Comptes Rendus*, 1948, *226*, 169.

Operational research.

So much has been said and written about the possible application of the methods of operational research to promote industrial production that a concrete example which has lately been instanced may be worth repeating. It is due to the Shirley Institute, the cotton industry's co-operative research establishment, and consisted in the quantitative investigation of the reasons for varying output in different mills. The method was to take each process separately, collecting figures for the amounts of cotton processed, numbers of workers, hours worked, types of plant, equipment and so on. The figures showed that for the same process and the same count of yarn, the number of man hours required per pound might vary by as much as three to one. By studying some of the apparently best and some of the apparently worst mills for any particular process, a good idea was then obtained of the reasons for these differences, practice in labour deployment, package size, lay-out or whatever it might be.

Up to a point, this could be described as 'merely common sense'. But it was of the essence of the inquiry that individual stages should be separately reviewed, and differences thus brought to light which, if overall efficiency had been made the yardstick, might have largely balanced out. The results, in any case, suggested that by bringing the practices of all mills up to the level of the best individual rooms, increases in output ranging possibly up to forty per cent might be obtained, with the same labour force and machinery. Whether this is called 'science' or 'common sense applied systematically and through figures', the fact remains that it needed an investigation by trained scientists familiar with the industry to show how much could be done. This example was quoted by Mr Herbert Morrison who, as Lord President of the Council, is responsible for the Department of Scientific and Industrial Research.

Sir Edward Appleton, as Secretary of the Department, has also given lately his own abbreviated definition of opera-

tional research. 'It is the arithmetic,' he said, 'of "what happens when we do what",' adding that 'recent studies have shown that in some cases industries can take immediate steps by which output could be increased by as much as 20 per cent'. Other industrial research organisations quoted as having taken a prominent part in investigations of the same type were the Iron and Steel Research Association and the Refractories Research Association which deals with the manufacture of heat-resistant materials. For comparison, it may be recalled that one of the more spectacular wartime successes of Operational Research – in doubling the effective anti-submarine patrol time of a Coastal Command Group – was achieved by no more abstruse methods than a rational and critical overhaul of maintenance procedures, based on statistics which were no more difficult of collection. A.W.H.

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Nullarbor, Australia.

A recent holiday expedition from Port Lincoln in South Australia across the Nullarbor plains to Perth by a party of Melbourne naturalists has whetted the appetites of Australian scientists for further expeditions into this scientifically interesting but little-known region.

Travelling in a capacious tourist coach, the party followed the route of one of the grimmest and most courageous journeys in the history of Australian exploration, that made in 1841 by Edward John Eyre, the first to cross the 1,000 miles of waterless desert country (plate 16) and reach the west coast by land. Water tanks at intervals of about 100 miles along the road through the desert to-day provide water, potable though mineralised, for travellers, but the tanks are not to be relied on in dry seasons.

There is no accommodation for travellers – only a few scattered homesteads, each the centre of a million-acre sheep run, where courageous hard working and resourceful settlers carry on Australia's pioneer traditions. With their

nearest neighbour some 70 miles away, these settlers must rely on the 'Flying Doctor,' summoned by pedal wireless, in cases of sickness. Their children are pupils of the 'School in the mail box,' Australia's celebrated system of education by correspondence for children who live in remote areas where there are no schools.

Beneath the surface of the Nullarbor plains lies a far-stretching underworld of limestone caverns (plate 17), deep lakes and waterways. The 500 feet deep limestone deposit is a survival from the miocene, when the plain was part of the bed of the sea. From these caves, the scientific party brought back two rare carved stalactites composed of mineral gypsum instead of the usual calcite: these gypsum stalactites have never before been found in Australian caves, though they were previously described in the Mammoth Caves of Kentucky and a small cave in Southern France. (See plate 18).

The holiday exploring party was organised and led by Mr Russell Grimwade, President of the Melbourne National Museum trustees and a leading Australian drug manufacturer. It comprised a forester, a zoologist, an anthropologist, an ornithologist, and seed-collector and a naturalist-journalist, as well as the entomologist director of the Melbourne Museum and a botanist of the staff of the Melbourne Herbarium. All brought back many interesting specimens, aboriginal chopping axes (plate 19), parasitic plants, metallic blue spiders which hunt metallic blue ants, and the strange plant *kingia* which grows a foot in a century and lives for several thousand years.

Whalemeat

The whale is not a fish. Like the cow, it brings forth its young as calves and nourishes them on milk. Like the cow, it is a warm-blooded animal, with the vestiges of four legs inside its flippers. And like the cow we eat it. A blue whale, 100 feet long, provides about 12 tons of meat – the muscle

or so, for a couple of hours at a stretch. This muscle is very fatty, and may contain anything from one to ten per cent of extractable oil. In the past it found a use, after the extraction of this oil, as a high-grade cattle food or a rich guano-type soil fertiliser; now the world food shortage has brought it on to the human dinner-table as a very valuable protein food. The blue whale's liver, which weighs about a ton, is also nutritionally important, for 3 per cent of it is oil rich in vitamin A.

But whalemeat, in its living state, is interesting from quite another point of view. The performance of the animal is so striking, both in speed and endurance of swimming, and in sheer strength, that one naturally wonders whether its muscles can possibly be the same in structure and function as those of the human body. Surely they must be much more efficient machines than those in our arms and legs. Otherwise, how could a whale tow a small steamer forward at seven miles an hour when its engines are racing full astern?

One way to compare the efficiency of machines is to compare the horsepower generated for a given weight of engine. Now human horsepower has already been worked out, and it seems that an athlete, like the dog, generates about a hundredth of a horsepower for each pound of muscle he has in his body. To get this result was relatively easy, because a man can be made to work away, for instance at pedalling a stationary bicycle, under laboratory conditions which permit of precise measurements. The whale is a more difficult case, and one or two assumptions have to be made, for instance that when towing the steamer it is doing as much work as would a submarine of the same shape and displacement. In other words, it is like a rigid steel body forging through the water, with a similar water skin friction resisting its passage. It may be, however, that the whale, being flexible and not rigid, and oiled all over, has less water-resistance to overcome, and wastes less energy in producing wake-eddies than the submarine. On the other

hand, experiments towing anæsthetised fish suggest that in fact they have much more friction, and not less, to overcome than a vessel of the same size and shape – but this may be due to their scaly rough surface.

Anyway, the assumptions probably do not completely spoil the calculation. They do not give the whale's *true* horsepower, but they do show whether this horsepower is a hundred times greater (or smaller) than the human. They are accurate to that extent, and after all, that is what accuracy is – always a relative matter, not an absolute thing. According to the experts, the value for the whale comes out at about 9 horsepower per ton of muscle, which is a figure lower than that for man, after all (four thousandths against one hundredth). So the answer seems to be that whalemeat is just like human meat, mechanically speaking, and the whale's fantastic power is the result only of its fantastic size. It has really no more kick to it than a cow.

Folic acid again

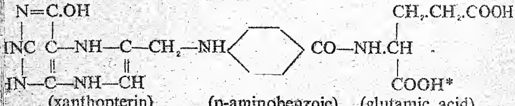
Since the report in an earlier issue of *Science News* of the discovery of this new water-soluble vitamin which is present in the leaves of plants as well as in liver and in yeast, further results have appeared to modify the original conclusions, and to justify a fresh account of the whole matter.

As in a great deal of modern vitamin research, workers got on the track of an unknown when they attempted to keep young chicks on a completely synthetic diet; one, that is to say, which contained only known proteins, fats, carbohydrates and minerals, and all the pure known vitamins. Something extra was needed in the food before the chicks would grow, something that prevented their getting anaemic. Experiments about the same time with various kinds of bacteria on simple casein media containing only known constituents, showed the same kind of result. Before the 'bugs' would grow a supplement had to be added. In the case of *Lactobacillus casei*, this was obtained from liver and yeast extracts; with *streptococcus fæcalis* it was found in

spinach. In the early stages there was nothing to show that L. casei factor and 'vitamin B_c' (for chicks) were the same – in fact, the different research groups thought they were after different substances. It was only as they purified the substances they were chasing that they found themselves coming to a similar conclusion. The new vitamin could be separated from protein, adsorbed on a special charcoal and eluted again, and so on, until there was obtained a product with a rather characteristic 'colour' (visible only in the ultraviolet, where only a camera can 'see' it). So gradually three supposed vitamins turned out to be forms of one.

There was also, as it happened, a fourth approach. Since 1931 Dr Lucy Wills has been interested in a special kind of anæmia which comes on during pregnancy in India, and is curable with liver, or extracts of yeast such as Marmite. It was found that a similar anæmia could be produced in monkeys by feeding them the sort of food eaten by the poor in the slums of Bombay, and this too was curable with liver, which therefore contained a new food factor, Vitamin M (M for monkey). Gradually it became apparent that there was little to choose between vitamin M and vitamin B_c, and in all probability they are identical.

The new vitamin occurs in at least three different variations, however, of which folic acid or pteroyl glutamic acid is the simplest. It is made up of a molecule each of xanthopterin (butterfly wing pigment), p-aminobenzoic acid (already known as a member of the vitamin B group), and glutamic acid (an important amino acid, already mentioned in these pages), thus:



(xanthopterin) (p-aminobenzoic) (glutamic acid)

The asterisk marks the point in the formula where varia-

may be three, i.e., two more attached at the asterisk; or even seven, as though the mechanism which makes the vitamin in the cell had stuttered or stuck in the groove and gone on repeating 'glutamic acid ... glutamic acid ...' These variations are not all physiologically interchangeable: the form with seven glutamic residues, for instance, is effective in the diet for chicks, but useless in the bacterial test. There exists an enzyme in animal tissues which breaks down the more complex forms to simple folic acid.

It was natural, in view of the effect of folic acid deficiency on the blood of chickens and monkeys, to try the effect of it on various human blood diseases. In this way it was discovered accidentally that folic acid would 'cure' pernicious anæmia. That is to say the anæmia would clear up and the blood remain normal as long as the correct dose of folic acid tablets was being taken. The quantity required was quite large – 5 or 10 milligrammes per day. At first it was thought that this would become the modern treatment, replacing the nuisance and expense of crude liver injections. But one aspect of the disease had been overlooked.

Pernicious anæmia itself is an illness in which there is a failure to produce the red cells of the blood; only a few are made, and they are abnormally large. Associated irregularly with this (the causal connection is obscure) there are nervous symptoms, grouped under the heading of subacute combined degeneration of the spinal cord. The nervous symptoms may be marked and the anæmia slight; or the anæmia alone may be present, followed only after some time by the nervous degeneration, which has nothing to do with the severity of the anæmia. It was early found that folic acid, unlike liver, would not affect the nervous side of the illness, but it took about two years of experience to show that people with anæmia only, and this anæmia successfully treated with folic acid, might develop subacute combined degeneration nevertheless. In other words folic acid was dangerous, because it lulled doctor and patient into a false sense of security. It affected the blood, but not

the nerves, and was only a half-cure. The truly curative substance present in liver extracts is still (March, 1948) a mystery: it is not folic acid, but it may be a chemical relative.*

In another illness, however, folic acid appears to be having a marked success. Tropical sprue is a disease with great diarrhœa, and an anæmia somewhat like the pernicious type. In a matter of days from the start of treatment, folic acid often arrests the diarrhœa, the health of the intestines improves, and the anæmia lessens. So far no fly in the ointment has been announced.

* Very recently Dr E. Lester Smith of Glaxo Laboratories, Middlesex, has announced the isolation from liver of a red pigment which is powerful in treating pernicious anaemia, though it does not contain folic acid. Simultaneously, workers at Merck Laboratories, New York, have isolated a crystalline "vitamin B_{12}" which is also powerful in treatment. The relation between the discoveries of the British and American workers, and further news of them, will appear in a later issue of *Science News*.

Minor Additions in Metals and Alloys

DR F. A. FOX

It is to-day becoming increasingly understood that our present level of engineering technology is in large part due to our skill in manipulating alloys. However, although it is well known that, where mechanical strength is needed, pure metals are too weak to do what modern engineering requires, it is not so widely understood that the amount of the critical alloying addition is often remarkably small. Most non-specialists have the haziest idea of how alloys are constituted, and tend to think of additions of tens per cent being necessary before metal B will have much effect on metal A. Some of the best-known and oldest alloys do contain large amounts of the added metal, as for example zinc in copper to make brass, and copper in gold to make the usual jewellery alloys. As, however, the science of metallurgy has developed it has become possible to do two things – first to begin to isolate the causes of differences in behaviour of apparently similar alloys, many of which sometimes refused, with a subtlety which seemed almost perversity, to do what was expected of them, and secondly, by inductive reasoning from observations of the first kind, to formulate fresh alloys which would have some new combination of desired properties. Two other activities, one old and one new, also go on in the metals research laboratories of the country. The first is the much-practised pursuit of trial-and-error; in the evolution of new alloys this method is widely used, is expensive but occasionally very rewarding: it is widely used because metal alloy problems are so complex, and because some of the fundamental guiding prin-

ciples are only just beginning to be discerned. The new thing is the study of metal physics in which physicists and metallurgists and physical chemists undertake fundamental researches into the behaviour of metals and alloys from the point of view of 'pure knowledge'.

The studies in metal physics and also in the more empirical spheres of industrial research have intensified in the last ten years, and the natural result has been to throw up many new ideas and to lead to the revision of many old ones. As is also to be expected, our ignorance becomes correspondingly more obtrusive.

One of the things that modern metallurgical research has emphasised is the importance, often decisive, of the part played by minor additions, constituents and impurities in ruling the properties of metals and alloys. In this context 'minor addition' means some element, phase or compound which is present to an amount less than 1 per cent of the whole; sometimes decisive influences are exerted by an addition or impurity present in far smaller amounts, of the order for example of 0·002 per cent.

The alloying additions which are made to the metals of commerce and industry are usually themselves metallic, such as chromium to nickel to make the elements for electric fires, or copper to aluminium to make duralumin. Some important alloying additions are, however, non-metallic and some are even gaseous. A technically important example is that of steel itself, in which the addition to the metal iron of, say, half of one per cent of the non-metal carbon produces an alloy enormously stronger and more versatile than the parent metal. Another non-metallic material present in steel has in recent years been found to have a profound effect on its heat-treatment behaviour and on its toughness and other properties, and that is alumina. The alumina occurs as a by-product of the deoxidation of the steel by aluminium additions during the steel-making process; the aluminium is itself oxidised, leaving behind minute amounts of alumina highly dispersed through the steel

The effective particles of alumina have not been positively identified even at the highest magnifications under the microscope, yet they affect the behaviour of the steel in which they occur in a radical way. The effect of gases on the behaviour of metals and alloys is often complex; generally they are harmful, but the addition of oxygen to copper is an example in the reverse direction; the presence of 0·010 per cent to 0·015 per cent oxygen in ordinary high conductivity copper (it occurs within the metal as copper oxide), is necessary to ensure that it will behave properly in manufacturing processes. Another example is provided by the use of carbon monoxide to improve the hardness of mild steel on the surface ('case-hardening'); the gas reacts with the iron, and iron carbide, the hardening constituent, is formed in the outer layers of the part which is to be hardened.

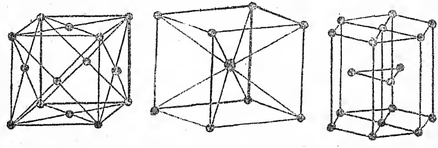
From the scientific point of view the interest is naturally focused on the picture which can be formed of the operative changes occurring within the structure of the metal.

Structure of metallic crystals.

It was long ago shown that metals are crystalline and that the ordinary alloys of industry are composed of a mass of crystals or 'grains,' which are clearly to be seen under the microscope if the piece is polished and suitably etched. It is also well known that the grains of a piece of metal, even though they do not advertise their crystalline symmetry by showing geometrically formed faces, have a beautiful internal regularity which can be revealed by X-ray crystallography or other means. Each crystal of a metal is built up by a symmetrical arrangement of atoms in space; these are packed together in the best way possible to accommodate the forces between them. The structure repeats indefinitely in all directions, and is bounded only by the limits of the piece itself, or, more usually, by the boundaries of the individual grain. The neighbouring grain has, of course, the same structure, but it is differently

oriented in space, and the grain boundary is a zone in which the atomic arrangement is locally not perfectly regular since it is one of transition from one orientation to another.

The geometry of the crystal structure or 'space lattice' is characteristic for each metal, although three common types



(a) (b) (c)

Fig. 25.—(a) Face-centred cubic structure: unit cell. (b) Body-centred cubic structure: unit cell. (c) Close-packed hexagonal structure: unit cell.

of symmetry are recognised. Two of these are included in the cubic system, in which the unit of atomic 'brickwork' of which the structure is built is cubic in form. The two common types of cubic 'unit cell' are the face-centred cube and the body-centred cube. In the former the unit cell is a cube, with atom at each corner and one in the centre of each face; in the latter, a cube with one other atom right in the centre of the cube itself (at the intersection of diagonals joining opposite corners). The third common type of unit cell is that termed 'close-packed hexagonal,' in which the unit is a hexagonal prism, with an atom in the centre of each end hexagonal face, and three others in symmetrical positions on the central plane parallel to the end faces (Fig. 25). Most engineering materials conform to one of these three types of structure, but the actual dimensions of the unit cell are characteristic of the particular metal (or alloy); minor deviations from these types also occur (for example some hexagonal metals are not close packed in structure, but are elongated or compressed axially from the geometrical ideal).

A great amount of research has been done in recent years on the detail of metallic lattices and the forces which hold them together; the dimensions are small, of the order of 10^{-7} to 10^{-8} cm. and the lattice forces large. The periodicity of properties shown in the table of the elements was an early pointer that atoms could not properly be considered as minute billiard balls, and that structures within the atom itself were critical. Metals are characteristically electropositive. This fact involves the implication that their atoms may be readily separated from one or more of the electrons which these contain. From the study of the forces in the space lattices of metals, the general picture has fairly recently emerged that the lattice points are occupied not by atoms, but by positive ions, from which one or more electrons have been separated; the electrons are more or less free to move in the interstices of this structure, forming what may be described as an "electron gas"; the electron gas or cloud is the decisive agency in holding the structure together, the ions themselves having a mutually repulsive effect. This picture is one for the most electropositive metals; other types of lattice bonding apply for those which are less characteristically "metallic" – for example the structures of arsenic, antimony, bismuth, selenium and tellurium are bound together by forces which are more like chemical linkages.

Mechanisms of alloying.

When an alloying addition is made to a metallic element, the question at once arises – how can the atoms of the alloying element be accommodated in the structure of the parent metal? Great numbers of investigations have been made over many years to follow the changes that occur when alloys are made; years ago the microscope and the cooling curve were the principal research tools and a great body of knowledge was built up with their aid. More recently X-ray and other techniques of modern physics have been adding to the data and are being also used to help formulate theories as to the

mechanisms of the observed effects. For many combinations of metals and over large ranges of temperature it has been found that the alloy structure scarcely differs from that of the parent metal, and that under the microscope only one type of crystal or grain is visible. Here the alloy is said to be a "solid solution", since the alloying addition must have somehow gone into solution in the parent metal. In other combinations of two metals, one may see under the microscope a mechanical mixture of two species of crystal or grain; these substances are only very seldom the pure constituent metals, they are themselves usually solid solutions of the two metals, often being of the kind – solid solution of B in A, mixed with solid solution of A in B. These various species of grains are called "phases" and they are usually assigned Greek letters to identify them; for example if one talks of an alpha-beta brass, one means a copper-zinc alloy of such a composition (for example, 60 per cent copper, 40 per cent zinc) which, it is found, has a structure consisting of the alpha phase together with the beta phase of that particular system. Phases usually exist over a range of composition; some may partake of the nature of intermetallic compounds; if they do, then their range of composition is, as would be expected, very limited.

If an alloying addition enters into solid solution its atoms must find places for themselves within the framework of the lattice of the parent metal. There are two possibilities – that the atoms of the alloying element should occupy lattice sites of the parent metal, or that the atoms of the alloying element should occupy spaces in the interstices of the parent lattice. These two types are called 'substitutional' and 'interstitial' solutions. The former is by far the more common; interstitial solutions are generally formed only by small atoms which can most readily be accommodated in the small spaces available. Carbon, nitrogen and hydrogen are the most common interstitial-solution forming elements, and that technically most important substance, the solid solution of carbon in iron, is interstitial: the carbon, which when

it does so, comes out of the solution as iron carbide, Fe_3C, reposes within the iron lattice, when dissolved, at points equidistant from three neighbouring iron atoms.

The effect of foreign atoms in the parent lattice is naturally to cause a greater or lesser distortion of its regularity in the neighbourhood of each intruder. The distortion varies with the nature of the added atoms, and with their numbers; when sufficient foreign atoms have been added to make the solid solution just unstable, then a new phase is formed if further additions are made, and this phase is of such a structure that it can accommodate the interatomic forces more 'economically' than the one which has just become unstable. The point at which a new phase appears is called a solubility limit; one may say for example that at room temperature aluminium can hold up to 0·2 per cent of copper in solution, and that above this solubility limit a new phase appears if more copper is added.

Important though the effects of added elements which go into solid solution may be, the influence of the presence of separate phases is equally great. Separate phases can occur in a variety of forms ranging from needle-like to globular shapes; they may occur within the grains of the parent metal or in the grain boundary, they may be in massive or in film-like forms, and their mechanical state of aggregation may have an influence as great as or greater than their 'inherent' effect associated with composition. In no field of metallic structures is this better exemplified than in 'age-hardening' in which the whole beneficial effect of an alloying addition is contingent upon its being present in the appropriate form.

Age-hardening.

Age-hardening is the name given to the spontaneous hardening of an alloy on standing after heat-treatment; the metal hardens with the passage of time, like its makers' arteries. This effect, so well-known in the duralumin type of alloy, is basically due to the fact that in the alloys showing it there is a solid solubility limit which increases as the temperature

is raised. At 548° C for example, metal A may be able to take 5·7 per cent of metal B into solid solution; but at room temperature it may hold only 0·2 per cent in solution, and above this limit some separate phase – say the β phase – tends to come out of solution. Suppose now an alloy of 5·7 per cent B in A is heated to 548° C and held at that temperature for long enough for all the β phase to dissolve and to produce a homogeneous solid solution; if the alloy is then quenched in water, the piece may cool so rapidly that there is no time for the β phase to come out of solution as it would otherwise do. The condition is then that of an alloy containing 5.7 per cent, and not 0.2 per cent, of B in solution at room temperature; the extra 5.5 per cent of B is said to be held in 'forced' solid solution. As a result, the alloy is unstable and spontaneous changes begin to take place in the direction of precipitation; these changes cannot occur very readily, since at room temperatures what may be called atomic mobility is not great, and not only is the time-scale of precipitation slowed down, but the state of aggregation of the embryonic precipitate is different from that associated with stability.

There has been much research, which is still continuing, on the nature of the incipient and rudimentary precipitates which form under these conditions in different alloy systems; for example in the aluminium-copper system, for which the above figures apply (this is the basis of the duralumin type of alloy) the changes taking place are complex and are on a scale well beyond the ordinary light microscope to resolve, although the normal precipitate in the un-heat-treated cast alloy is readily visible under the microscope. The effect of the elementary type of precipitation occurring under age-hardening conditions is observed in many alloying systems; it is to cause a distinct, and sometimes a technically decisive, hardening and strengthening of the alloy, and electrical and other physical properties are also affected. These changes are wholly due to the special state of aggregation of the alloying addition; the alloy before

the solution and ageing treatment is of the same chemical composition, but the second phase, when in massive form (massive at least on a microscopic scale) has a relatively small strengthening effect on the structure. The highly dispersed incipient precipitate exercises its great hardening effect by some mechanism of distortion of the parent lattice, which makes the metal more resistant to deformation (that is, harder) by making less easy that slipping movement on atomic planes by which a metal deforms under load. The details of the lattice distortion mechanisms vary from alloy to alloy according to the nature of the component metals.

Effects of minor additions.

The technical interest of minor additions to metals and alloys lies in four main fields; first, the addition may have some peculiarity which makes it so potent, that although minor in quantity it constitutes the main alloying effect of the system; second, it may be added to neutralise the harmful effect of some impurity which it is not practicable or economic to eliminate; third, it may be added to counteract some undesirable behaviour of an otherwise useful alloying addition already present, or finally, it may be added to modify some specific physical or chemical property of the metal to a maximum (or a minimum) extent. These effects the minor addition must achieve by going into solid solution in phases already present, or by causing a separate phase to appear.

Light alloy examples.

A good example in the first field is provided by the recently investigated alloys of magnesium and zirconium, some of which are now being developed for industrial application. Pure magnesium is not used for engineering purposes, since, unalloyed, it is too weak. One of the reasons for this weakness appears to be connected with the fact that it solidifies with a large grain size; it is not only a general fact of observation that metals and alloys tend to be weak if their grain structure is coarse, but it is found that magnesium alloys as

a class are especially badly affected if their structures are coarsened by any means. Research during the last few years has shown that zirconium has a large grain-refining influence on the structure of cast metal and if about 0·7 per cent of the alloying addition is present in an effective state, the grain size is reduced by a factor of ten or more. This is illustrated by plates 21 and 22; plate 21 shows the grain structure of pure cast magnesium as seen under the microscope at a magnification of 50; plate 22 shows the grain structure of a cast magnesium alloy containing 0.7 per cent of zirconium, at a similar magnification. The latter has mechanical properties which are very much improved, and its ability to deform before breaking is at least doubled. It is probable that the alloy owes its improved properties to some 'inherent' effect of the zirconium in solid solution as well as to the more mechanical effect of the reduction in the size of the grains. Not more than about 0.75 per cent will go into solid solution in magnesium; this is remarkable since from many points of view theory would suggest that a wide composition range should exist for the solid solution. It almost seems as if the zirconium, although not dissolving to such an extent as might be expected, crammed all its probable effect into the restricted solution range of about 0.75 per cent. A similar amount of zirconium enters into solid solution in alloys of magnesium containing 2 per cent to 6 per cent zinc, and also has a striking effect in refining the grain, strengthening the alloys and making them much more capable of being deformed before breaking; the latter is important technically as it means that forms such as sheet and forgings can much more readily be made from the ingot. Its useful effects increase more or less uniformly up to the solubility limit of zirconium in the parent material; further additions give no increased benefit, and in fact they are probably harmful, as the extra alloying element causes a massive new phase to appear which is likely to have a bad effect on the corrosion behaviour by favouring the creation of local galvanic cells within the metal.

The alloys of aluminium have been the subject of intensive research for very many years, and strong grain refinement has been observed to follow from minor additions of titanium, columbium and boron; but in this field the minor addition which might be classed as having the effect of a major alloying element is sodium, when added to the aluminium-silicon alloys. The normal alloy containing 11 per cent to 13 per cent silicon is distinctly weak and brittle under impact if it is cast in a sand mould to make a piece of any size. If however, 0·05 per cent of sodium is added to the molten alloy just before pouring, the metallographic structure is greatly refined and the mechanical properties of the casting are so much improved that the treated (or 'modified') alloy may safely be used for engineering parts such as crankcases and cylinder blocks. Some of the sodium is lost in the addition, and only about 0·015 per cent appears in the finished casting. There are many interesting points about 'modification', chief among which is the fact that the alloy shows a modified structure even in the absence of sodium if it is quickly cooled; in other words, a thin sectioned piece cast into a metal mould would not require the addition of sodium to produce a modified micro-structure and good mechanical properties. *The sodium, therefore, appears to be* acting in some way like a super-cooling agent; it also delays the crystallisation of the silicon, since it is found that modified alloys solidify at lower temperatures than do the normal ones. If an alloy supercools it is usually for the same reason that the super-saturated hypo solution in the schoolboy experiment remains liquid – because of absence of inoculants. In the solidification of metals only specific inoculants are effective and it is probable that sodium has its remarkable effect by forming an 'insulating' coating on minute particles of impurities which, in the unmodified alloy, can act as inoculants and cause earlier and coarser solidification.

Counteractant additions.

An example of researches in the second field is provided

by the harmful effect of small amounts of bismuth as an impurity in copper. If copper contains more than about 0.005 per cent of bismuth its ability to be hot-rolled falls very seriously, and as hot rolling is the standard way of making copper sheet, this influence is economically most undesirable. Copper refined by an electrolytic process contains negligible quantities of bismuth, but it is always present in copper which has not been treated in this way, and no other satisfactory way of removing small quantities of bismuth is available. The amount of bismuth entering solid solution in copper is less than 0·002 per cent; any bismuth occurring above this limit in pure copper does so as metallic bismuth itself. Its strikingly harmful effect is exerted because its presence gives rise to small quantities of liquid metal when the copper is heated for hot-rolling; the liquid spoils the continuity of the metal and causes cracking; it also adversely affects cold-rolling because the bismuth, which is weak, tends to take up film-like forms between the crystals of copper, destroying their cohesion. If the copper contains oxygen, as it often does, then the bismuth occurs as the less harmful oxide, Bi_2O_3; above 800° C, however, metallic bismuth is formed. The approach to the problem has had to be along the lines of finding some addition agent which will neutralise the harmful effect of the bismuth, by combining with it to convert it into some relatively harmless form or compound.

Australian research showed that one agent which could be used to eliminate, at least at room temperature, the brittleness of bismuth-contaminated copper, was phosphorus. The use of this element is an easy matter for the copper refineries, since copper is often deoxidised with phosphorus, and all that is required is to ensure that there is enough phosphorus left in the metal to neutralise the bismuth; it seemed probable that the phosphorus worked without combining with the bismuth, but by causing it to assume a globular, non-film-like form, perhaps by some surface-tension mechanism.

phosphorus required (0·1 per cent to neutralise 0·011 per cent of bismuth) would itself interfere with the hot-working behaviour. Another line of research has been pursued in this country and a solution has been forthcoming which is effective for high as well as room temperatures. The attack was to test the effect of alloying additions which form stable compounds with bismuth; among these was lithium, which forms the compound $BiLi_3$ with a melting point of 1145° C. It was found that an addition of 0·036 per cent lithium entirely eliminated the harmful effects of bismuth up to 0·01 per cent. The formation of the high melting-point compound would naturally lead to the elimination of the liquid phase so harmful to the cohesion at high temperatures. The addition of lithium is also effective in preventing the bismuth embrittlement of copper-tin and copper-zinc alloys.

Another example of the 'set a thief to catch a thief' technique occurred in zinc alloy research work. Some years back a serious trouble with zinc alloy die-castings was that they were found to weaken spontaneously with time; they became brittle, and even sometimes disintegrated after a few months service. It was found that the trouble was due to the presence of minute amounts of tin, lead and cadmium in the alloy, which caused it to become susceptible at the grain boundaries to the effects of moisture and slight heat, and thus prone to atmospheric corrosion spreading along them, which caused weakening and disruption of the metal. The amount of tin which could have this unwelcome effect was particularly small – of the order of 0·002 per cent. As lead and cadmium were present in the crude metal, the problem of dealing with them was in the last resort a matter for experts in extraction of the zinc; in the meantime a temporary solution was found, however, by the addition of magnesium to the casting alloys. It was found that about 0.1 per cent of magnesium would make the alloys fairly stable to tropical atmospheric conditions provided the concentration of lead, tin and cadmium were not too high (0.005 per cent for cadmium and tin, and 0.010 per cent for

lead). At the same time the general corrosion resistance of the zinc alloys for casting was raised by eliminating the 3 per cent copper which they used to carry, and thus making them mainly a zinc-aluminium alloy. The exact mechanism of the improvement caused by the magnesium addition is not clear, but it is probable that it operated by the formation of harmless magnesium-containing compounds in which were 'mopped up' the dangerous impurities. The whole problem has now passed into limbo by the development of a new process for the extraction of zinc, which gives metal of higher purity than 99.99 per cent; although the woodpile should no longer contain the niggers, 0.03 per cent of magnesium is still added to the alloys in case of accidental contamination.

Preventing "weld decay".

Although it is possible to make a stainless steel without chromium there are many excellent reasons why our standard stainless steels should contain that element, and one of the best-known compositions for stainless steel is 18 per cent chromium, 8 per cent nickel, together with a small amount of carbon – say 0·1 per cent. In steel of this composition the chromium confers the bulk of the 'stainlessness', and if anything happened to withdraw the chromium, even locally, the steel would not be able to resist corrosion in the way expected of it. It turns out that this very thing can occur under some conditions. The structure of stainless steel is such that under most conditions the carbon present remains in solid solution; if however, the steel is heated in the range of 550° C – 750° C most of the carbon will come out of solution in the form of free carbide which appears at the grain boundaries. The carbide which forms in this steel is mainly chromium carbide (Cr_4C), although some iron and nickel carbides also form, and every 0·1 per cent of carbon in it is combined with 15 to 18 times that amount of chromium. When the steel is heated in the critical temperature range the carbon, having a small interstitial atom, diffuses quickly

and comes from the interior of the crystals to reach the grain boundaries, at which precipitation occurs; the chromium atom, at these temperatures, diffuses to the 'rendezvous' far more slowly, and consequently the chromium making up the precipitate is drawn mainly from the outer portions of the crystals, near the grain boundaries. Since these outer layers must contribute enough chromium to supply 15 to 18 times the amount of carbon coming from the whole of the bulk of the crystals, they suffer a severe loss of chromium, and as a result the corrosion resistance of the metal is locally destroyed. Stainless steel which is in this condition, if subjected to corrosive conditions, suffers rapid attack at the grain boundaries, and in time may disintegrate. This effect was originally noticed in stainless steels which had been welded, and it was termed 'weld decay' in the shops, 'intergranular corrosion' in the laboratories.

This bad effect of an otherwise useful alloying element could be countered by three methods: by reducing the carbon content so that precipitation does not occur, by introducing some other element which has a greater affinity for carbon than has chromium, or by suitable heat-treatments. The first is not practicable from a manufacturing viewpoint, and the last is often not economic or convenient, especially for welded pieces. The search for the antidote element was, however, successful, and three answers were found. The most commonly used alloying addition to prevent intergranular corrosion of stainless steel is titanium, which has the required high affinity for carbon and forms a carbide TiC. It is found that if 0.5 per cent of titanium is present, essentially all the carbon which precipitates does so as TiC, and the chromium is left behind in solid solution to protect the steel against corrosive attack, which thus becomes immune from weld decay. In welding, however, the presence of titanium in the welding rod does not necessarily produce weld metal which is immune from intergranular corrosion, since a large part of the titanium may be oxidised during the welding, and the loss will be critical if several

crossing or overlapping welds have to be made. In these circumstances the alternative solutions may provide better results – 0.75 per cent of columbium or 2 per cent silicon – since these elements do not suffer such loss in the welding operation, and consequently can more readily ensure that the chromium is kept in its proper 'defensive' place in solid solution.

Restriction of grain growth.

Examples of the use of minor additions to modify specific physical or chemical properties of metals and alloys are numerous. Interesting illustrations lie in a field allied to that of grain refinement touched upon earlier; this is the restriction of grain growth. It is a general rule that metals which have been mechanically worked (rolled, forged, etc.) may tend to undergo grain growth when they are heated, i.e., certain grains grow by swallowing their neighbours. It often turns out that severe grain growth is undesirable since it is accompanied by loss of strength and hardness. If it is an unavoidable part of some operation that a metal or alloy has to be submitted to a high temperature, then it becomes desirable to try to restrict the resultant grain growth in some way, to avoid its weakening effects. A familiar example of metal exposed to very high temperature is that of the tungsten filament wire in ordinary electric lamps which runs at temperatures well over 2,000°C. If tungsten without any additions is used for filament wire, the grains become enormous as the lamp's life continues; as a result the metal becomes brittle and the grain growth causes distortion or sagging under the filament's own weight. An addition is therefore made to the tungsten during the manufacture of the wire, of an agent capable of obstructing the growth of the grains; 0·75 per cent of thorium oxide (thoria) is very effective in this way, being insoluble in the tungsten, and when finely distributed throughout the structure the particles present a durable mechanical obstruction to grain

permits the production of filament wire with a much increased service life.

Before a worked metal undergoes grain growth when it is heated, it usually recrystallises – that is, among the crystals which were distorted by the working process, appear tiny new ones, which are not distorted; these begin to grow as the temperature is raised further, and they finally obliterate the old structure. The metal is then said to be 'completely recrystallised'. Most metals are much strengthened by being worked, and recrystallisation causes the increased strength to be lost with the obliteration of the old crystals. Pure copper is rather weak, but is valuable for its high electrical and heat conductivity; for some uses in which strength is needed as well as good conductivity, it is used in the worked state, such for example as hard cold-rolled sheet; suppose, however, that this copper has to be soldered; the heat of the soldering operation will perhaps be enough to cause recrystallisation and loss of the desired extra strength put in by the working. Here the problem is to find an alloying addition which will raise the recrystallisation temperature, thereby avoiding the softening, but which will not interfere with the good conductivity of the metal. Copper is most sensitive to minute traces of impurities, many of which cause a great drop in conductivity; the selection of permissible alloying additions is, therefore, very restricted. The answer to the problem is provided by the addition of about 0.1 per cent of silver. This element itself has a very high electrical and thermal conductivity, and has a negligible adverse effect on these properties in copper; it also has no bad effect on the strength of the worked copper, but 'postpones' to much higher temperatures the softening effects of heating for operations like soldering. This small addition of silver thus permits the use of copper when strength and high conductivity are required, and when a high temperature is to be met during manufacture.

This short and rather simplified review will perhaps help

to bring home to non-specialists the idea that the metal laboratories are to-day very much concerned with 'minor-addition-metallurgy'.

[*Beginners in this field may find it helpful to read first the article* Metals by Sir Laurence Bragg, which appeared in *Science News* 1.—Ed.]

GLOSSARY

BIRTH RATE: This is calculated as

$$\frac{\text{the number of babies born during one year} \times 1000}{\text{the number of individuals alive, half-way through}}$$

Thus, if the year is from January 1st to December 31st, the total number of people of all ages alive on June 30th, is the figure required for the denominator (see also under *Fertility*).

CASEIN: The chief protein present in milk.

COEFFICIENT OF EXPANSION: Different materials expand and contract to differing extents on heating and cooling. These differences between substances can be described quantitatively by comparing the actual expansions of unit lengths (1 cm) of each material when the temperature is raised by 1°C. The numbers so obtained are called coefficients.

DEATH RATE: The crude death rate for a population is

$$\frac{\text{the number of deaths registered in the year} \times 1000}{\text{the total number of people alive, half-way through}}$$

Here the word 'population' denotes a group living within definite geographical boundaries. Consequently, to get the correct number of deaths, allowance must be made for residents who die while away from home, and the deaths of visitors from abroad must be discounted.

Specific death rates in general are calculated in the same way, but refer only to one group of the population, e.g., teen-agers, bus-conductors, women, comparing the number of their deaths with the number of them all alive.

FERTILITY: An estimate of the extent to which people can and do multiply. Thus the Birth Rate (*see above*) is an attempt to measure it, but one liable to mislead since no account is taken of the number of women in the population of the right age to have children.

Therefore the Fertility Rate is sometimes calculated:

$$\frac{\text{number of legitimate births} \times 1000}{\text{number of married women between 15–45 years old}}$$

in which case an illegitimate birth rate must also be separately calculated on the same lines, to get a true final picture.

LIFE TABLES: How long can you expect to live? Quite a number of people besides yourself are interested in this question, Insurance companies for instance, and Government planners trying to arrange the future. If you are already ninety when you read this

you know that the time is not long – much shorter than if you are only ten. A life table shows the probable expectation of life of a person at any age, calculated continually from the observed ages at which people die. Owing to the progress of public health measures and of medicine and surgery, and perhaps for other unknown causes, the ages at which most people die continually alter (people on the average live longer now than they used to a hundred years ago), so that the life table must be always brought up to date.

MAGNETIC SUSCEPTIBILITY: A coefficient which indicates how easy it is to magnetise a given substance. Every schoolboy knows that iron is easily made into a magnet (i.e., has a high susceptibility). Whereas aluminium, for instance, cannot be so treated, and therefore has a very low value.

About Our Contributors

A. E. Bell, Head of the Science Department, Clifton College, is a chemist who has become equally interested in the history of Science. His book on *Christian Huygens* appeared earlier in the year, and his chief interest is in the educational problem arising through the need for scientists of wide culture in modern civilisation.

I. W. Cornwall was born in India in 1909. He is a graduate of Cambridge and holds the Academic Diploma in Prehistoric Archæology of the University of London, where he occupies the post of Secretary at the Institute of Archæology. His chief interests are in human evolution, the skeletal remains of early men and sub-men, and the study of their environment and equipment as shown by Geology, Palæontology and Archæology.

J. L. Crammer has been editor of *Science News* from the first issue, originally under a pseudonym. He has had experience of Service life and of journalism, is a Science graduate of Cambridge, where he has done research, is medically qualified, and has practised medicine. He is now twenty-seven.

Frank Dickinson is a contact lens practitioner who has written several technical and general articles on the work which he has been doing for the past ten years. He has lectured extensively abroad and at training centres and technical colleges here, and is a member of the Council of the Contact Lens Society.

Francis Fox graduated in Metallurgy at Birmingham, and took his first job on a gold mine in West Africa. He has been engaged in metallurgical research ever since he returned to this country, and is best known for his publications on magnesium alloys, for which he was awarded his D.Sc. He is at present Deputy Director of the British Welding Research Association.

A. W. Haslett is a Cambridge graduate, who has made scientific journalism his career. He is Editor of *Science Today*, and for some months past has been a regular speaker in the B.B.C. Forces Educational Programme.

Robert René Kuczynski, who died at the end of last year, was one of the greatest demographers of our time. The University of London appointed him in 1939 to the first Readership in Demography established in this country, and in 1944 he was appointed demographic adviser to the Colonial Office. His publications include *Balance of Births and Deaths* (1928 and 1931), *Fertility and Reproduction* (1932),

and *The Measurement of Population Growth* (1935). One of his special contributions towards the correct interpretation of population figures was his exposition of a statistical device for estimating whether a given population is tending to increase, decline or remain stationary, by means of two simple indices, the gross and net reproduction rates.

Stephen Lestrange is the pseudonym of a young physician who has been trained in both Neurology and Psychiatry. He is interested primarily in the interaction of mind and body, and is now engaged in whole-time research.

K. L. Loewenstein is a young chemist at present working with a glass manufacturing firm. Apart from chemistry, his particular interests are music and economics.

Maurice Oudot is the Head of a Department of the 'Quinze-Vingts' Hospital, a famous eye Clinic in Paris.

Ernest Tillotson was educated at Leeds University, where he acquired an interest in probing into the earth deeper and deeper, first with a hammer and then assisted by the apparatus used by physicists. He is honorary secretary of the British Association Seismological Committee, a member of the American Geophysical Union, and seismological correspondent to *Nature*. He is married and has one son.

INDEX

GENETICS

BY H. KALMUS

Though genetics is the youngest of the biological sciences, it is exciting more attention among both scientists and layfolk at the present time than any other branch of biological inquiry.

It has grown so fast, and in so spectacular a manner, that the majority of scientists, and even of biologists, cannot keep abreast of it; in consequence it has won an undeserved reputation for being difficult to understand. How undeserved, will be apparent to every reader of this book; for Dr Kalmus and his collaborator, Miss L. Crump, in comparatively small space, here set out in simple language the main principles of the science so clearly and concisely that every reader, however previously ignorant of its axioms and achievements, will be able to follow.

Part of the supposed difficulty, perhaps, resides in the special terminology which genetics has created to meet its special needs. But no one need be deterred from making a closer acquaintance with genetical principles on this account; the authors give the fullest explanations of the special terminology, and clones, alleles, polyploids will hold no mysteries for the readers of their pages.

What factors of biological make-up are inherited, in plants, animals, and man; how they are inherited; how mutations and variations arise and are transmitted; the importance of genetical knowledge to the gardener, farmer, stock-breeder, and human parent; all these matters are discussed and explained, and the text is elucidated by a number of simple diagrams.

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